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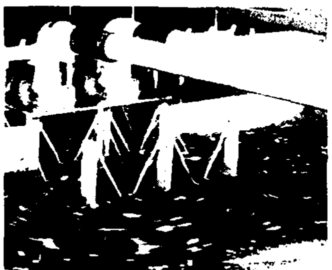

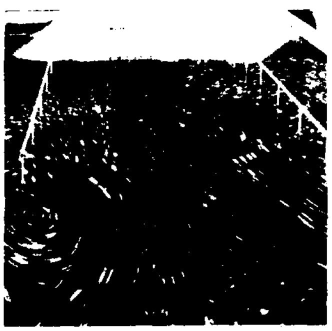

CINQUE HOMMES, JONES CUTOFF, BOIS BRULE AND MISSOURI CHUTE PUMPING STATIONS; PERRY COUNTY, MISSOURI, AND RANDOLPH COUNTY, ILLINOIS

Hydraulic Model Investigation

by

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

June 1988

Final Report

Approved For Public Release; Distribution Unlimited

HYDRAULICS LABORATORY

Prepared for US Army Engineer District, St. Louis
St. Louis, Missouri 63101-1986

88 7 2

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report HL-88-13	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES Hydraulics Laboratory 6b. OFFICE SYMBOL (If applicable) CEWES-HS-S	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39180-0631	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION USAED, St. Louis 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code) 210 Tucker Blvd N. St. Louis, MO 63101-1986	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Cinque Hommes, Jones Cutoff, Bois Brule, and Missouri Chute Pumping Stations; Perry County, Missouri, and Randolph County, Illinois; Hydraulic Model Investigation

12. PERSONAL AUTHOR(S)
Fletcher, B. P.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM 1977 TO 1979	June 1988	95

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Flow distribution Pump sump Submergence Suction bell

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The four pumping stations (Cinque Hommes, Jones Cutoff, Bois Brule, and Missouri Chute) provide flood protection for about 26,800 acres of highly productive bottomland.

Satisfactory hydraulic performance was obtained in the sumps for the Cinque Hommes and Jones Cutoff pumping stations by either extending wing walls from each side of the structures or by moving the timber trashrack closer to the sump and enclosing the rear and sides of the sump.

Following the model studies of the sumps for Cinque Hommes and Jones Cutoff pumping stations, the design of the sump and trashrack for the Bois Brule pumping station was revised due to the high cost of building and maintaining the timber trashrack. The revised design, consisting of a classical trashrack and free-standing side and rear walls, performed satisfactorily.

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20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

19. ABSTRACT (Continued).

The model of the Missouri Chute sump indicated unsatisfactory flow due to adverse currents in the sump generated by lateral flow from a side channel located normal to the main channel. The mouth of the side channel was relocated farther upstream and satisfactory performance was obtained.

The designs of the 45-deg saxophone outlets and channel configurations for the four pumping stations were similar. Design guidance for the size and extent of riprap needed in the exit channels was determined from the models.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers (OCE), US Army, on 29 June 1977, at the request of the US Army Engineer District, St. Louis (LMS).

The study was conducted during the period June 1977 to December 1979 in the Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), under the direction of Messrs. H. B. Simmons, Chief, HL, and J. L. Grace, Jr., Chief, Hydraulic Structures Division, respectively, and under the direct supervision of Mr. N. R. Oswalt, Chief, Spillways and Channels Branch. The project engineer for the model study was Mr. B. P. Fletcher, assisted by Messrs. J. Markussen and B. Perkins, Spillways and Channels Branch. This report was prepared by Mr. Fletcher and edited by Mrs. N. Johnson, Information Products Division, under the Interpersonnel Agreement Act.

During the course of the investigation, Messrs. J. Robertson and S. Powell of OCE; J. Harz III, J. McCormick, L. Eckenrod, E. Middleton, D. Marshall, and E. Walker of the Lower Mississippi Valley Division (LMVD); F. Bader, D. Hoy, T. Moore, E. Pucel, E. Middleton, D. Marshall, and J. Hetizmann of LMS; B. Paulette and W. Brugger of Stanley Consultants; and L. Rader, S. Haldiman, and W. C. Tailaferro of Tailaferro and Brown visited WES to discuss the program and results of model tests, observe the model in operation, and correlate test results with design studies.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
feet of water (39.2° F)	2,988.98	pascals
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (force) per foot	14.5939	newtons per metre

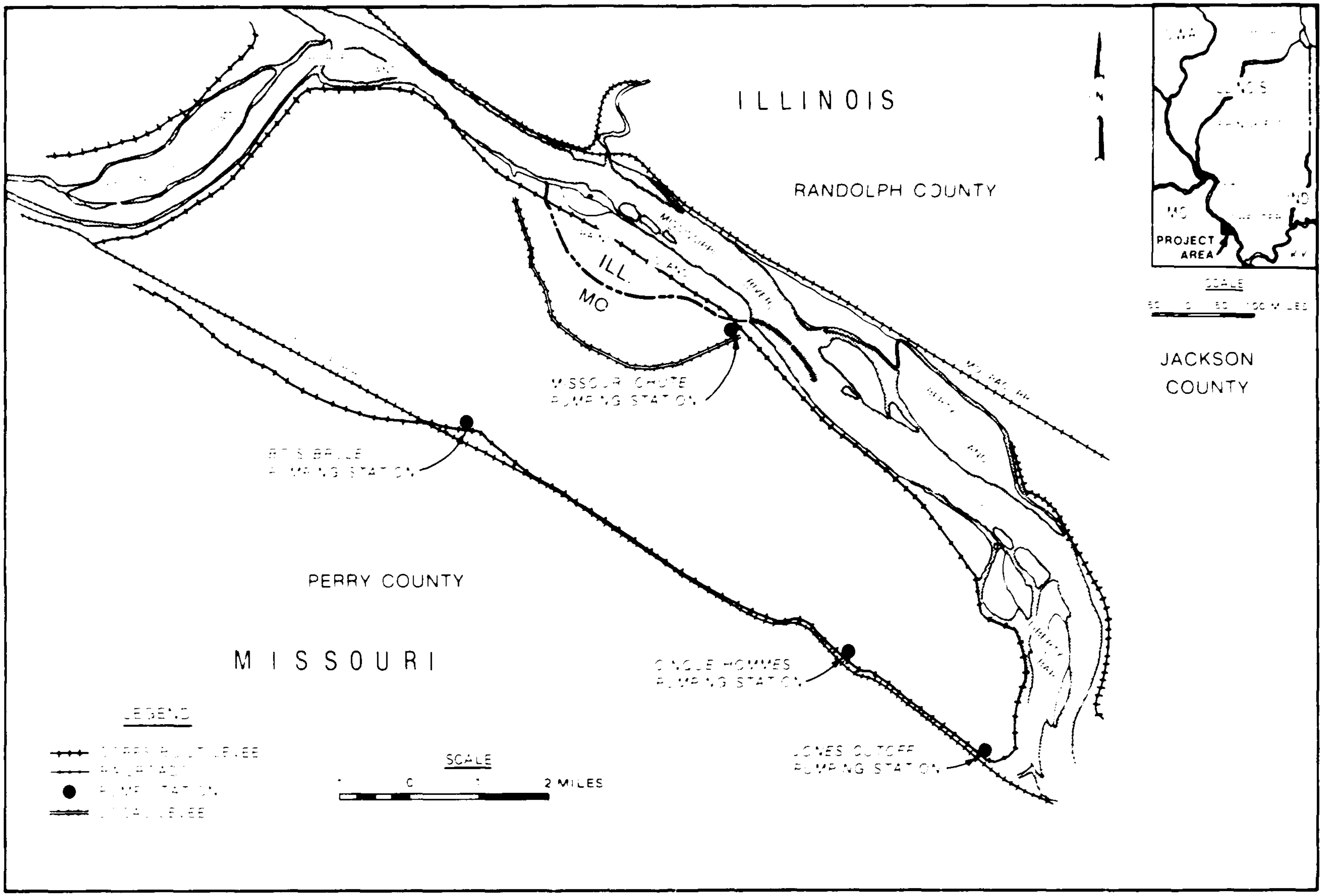


Figure 1. Vicinity map

CINQUE HOMMES, JONES CUTOFF, BOIS BRULE, AND MISSOURI CHUTE PUMPING STATIONS; PERRY COUNTY, MISSOURI, AND RANDOLPH COUNTY, ILLINOIS

Hydraulic Model Investigation

PART I: INTRODUCTION

Prototype

1. The project plan consists of four agricultural type pumping stations located on the right bank of the Mississippi River about 70 miles* south of St. Louis, Missouri (Figure 1). The pumping stations provide flood protection for about 26,800 acres of highly productive bottomland. The pumping stations are designed for the following number of pumps and flow capacities: Cinque Hommes (Plate 1) has two 62.5-cfs pumps; Jones Cutoff (Plate 2) contains two 62.5-cfs pumps; Bois Brule (Plate 3) contains three 72.0-cfs pumps, and Missouri Chute (Plate 4) has one 50-cfs pump.

2. All stations are located adjacent to gravity discharge lines. Plans for each station prior to the model study include an entrance channel with a timber trash-control structure. A typical trashrack and operating platform are shown in Plate 5. Each pumping station facility consists of a landside, pile-founded, operating platform with steel discharge pipes over the levee and a riser side-outlet structure. Discharge pipes over the levee are provided with siphon breakers. The discharge conduits terminate with saxophone discharge outlets that discharge into rock-lined channels.

Purpose and Scope of Model Studies

3. The model studies were conducted to evaluate the flow characteristics of the sumps and discharge outlets and to develop practical modifications required for improving the distribution of flow to the pump intakes and energy dissipation and channel stability at the discharge outlets. The scope of the

* A table of factors for converting non-SI to SI (metric) units of measurement is presented on page 3.

model investigation involved studying the magnitude and direction of currents approaching the pump intakes and the hydraulic characteristics of flow entering the pump intakes.

PART II: MODELS

Description

4. Four models of sumps were consecutively investigated concurrent with compatible consecutive evaluation of four models of each saxophone discharge outlet. Each sump model was constructed to a linear scale ratio of 1:10 and simulated a 300-ft length of the approach channel, trashrack, sump, and pump intakes (Figures 2-4). The sump model for the Jones Cutoff station was almost identical to the Cinque Hommes station shown in Figure 2. Each model of the discharge outlets was constructed to a linear scale ratio of 1:10 and included the saxophone outlets and approximately 100 ft of the riprap-lined exit channel (Figures 2 and 3).

5. Flow through each pump intake and outlet was provided by individual pumps that permitted simulations of various flow rates through one or more pump intakes or outlets. Water-surface elevations were measured with point gages. Velocities were measured with a pitot tube and a turbine current meter. Current patterns were determined by injecting dye into the water and sprinkling confetti on the water surface. Pressure fluctuations at the pump intakes were measured by 5.0-in.-diam (prototype) electronic pressure cells (Figures 5 and 6) mounted flush with the floor of the sump directly below the center line of the pump intake. A pressure fluctuation 4 ft or greater is considered unacceptable. Swirl in the pump intakes was indicated by a vortimeter, free-wheeling propeller with four zero-pitched blades, located inside each pump intake at the approximate position of the prototype pump propeller (Figure 6). Swirl angle, θ , is defined as the ratio of the blade speed, V_θ , at the tip of the vortimeter blade to the average velocity, V_a , for the cross section of the suction column. The swirl angle, θ , is computed from the following formula:

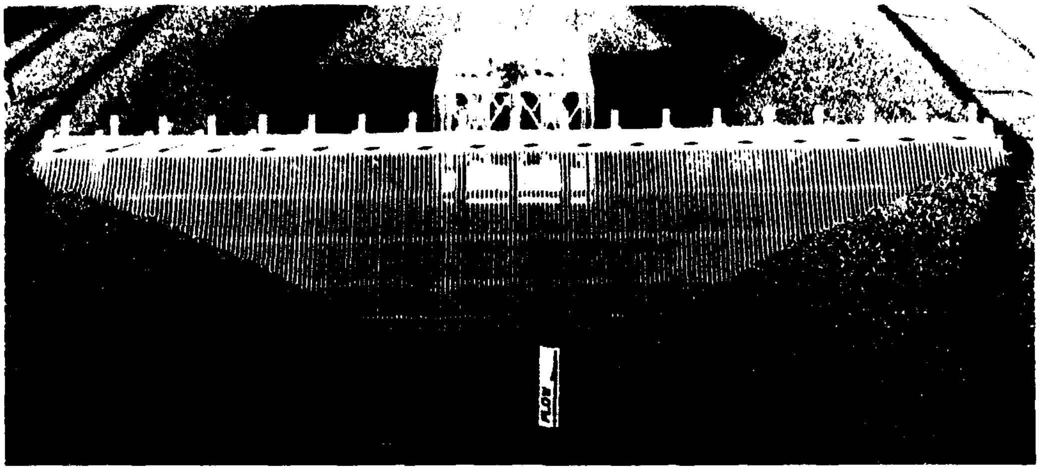
$$\tan\theta = \frac{V_\theta}{V_a} \tag{1}$$

where

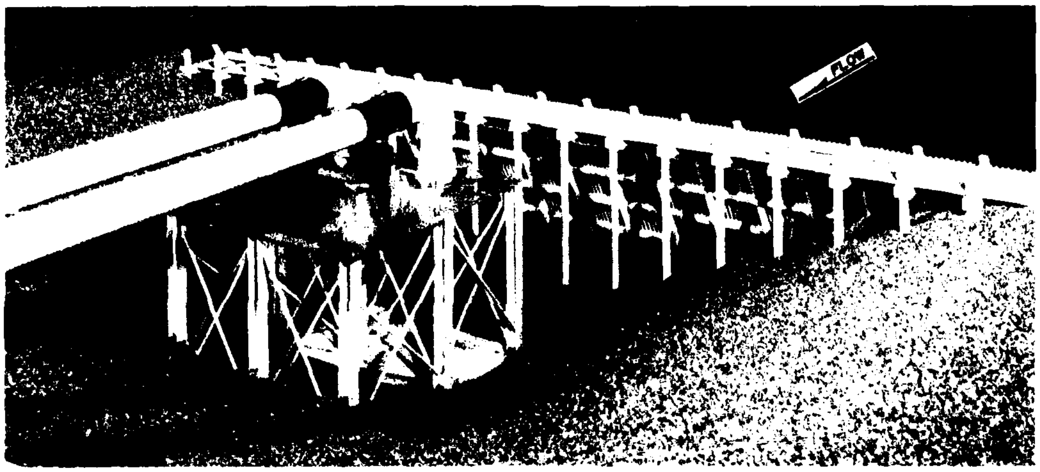
θ = swirl angle, degrees

$V_\theta = \pi dn/60$

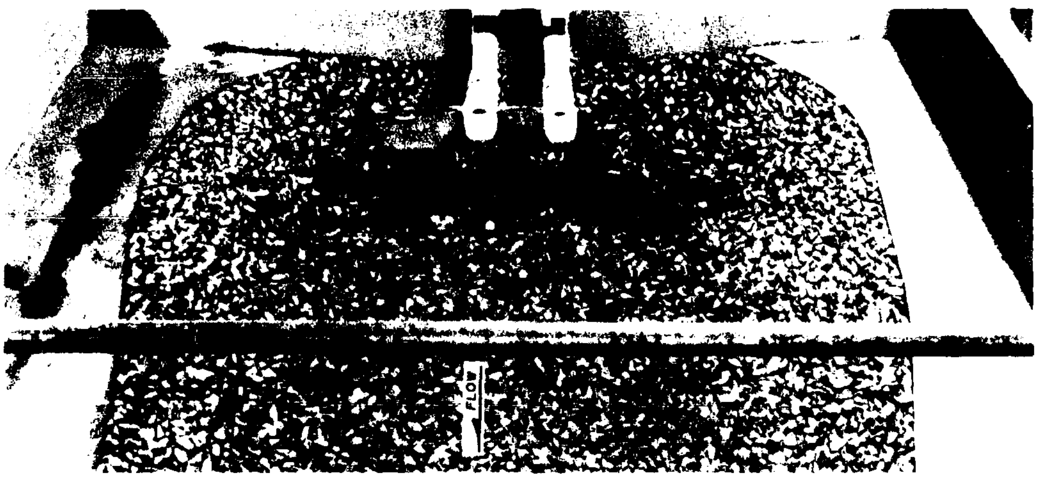
d = suction column diameter used for blade length, ft



a. Upstream view

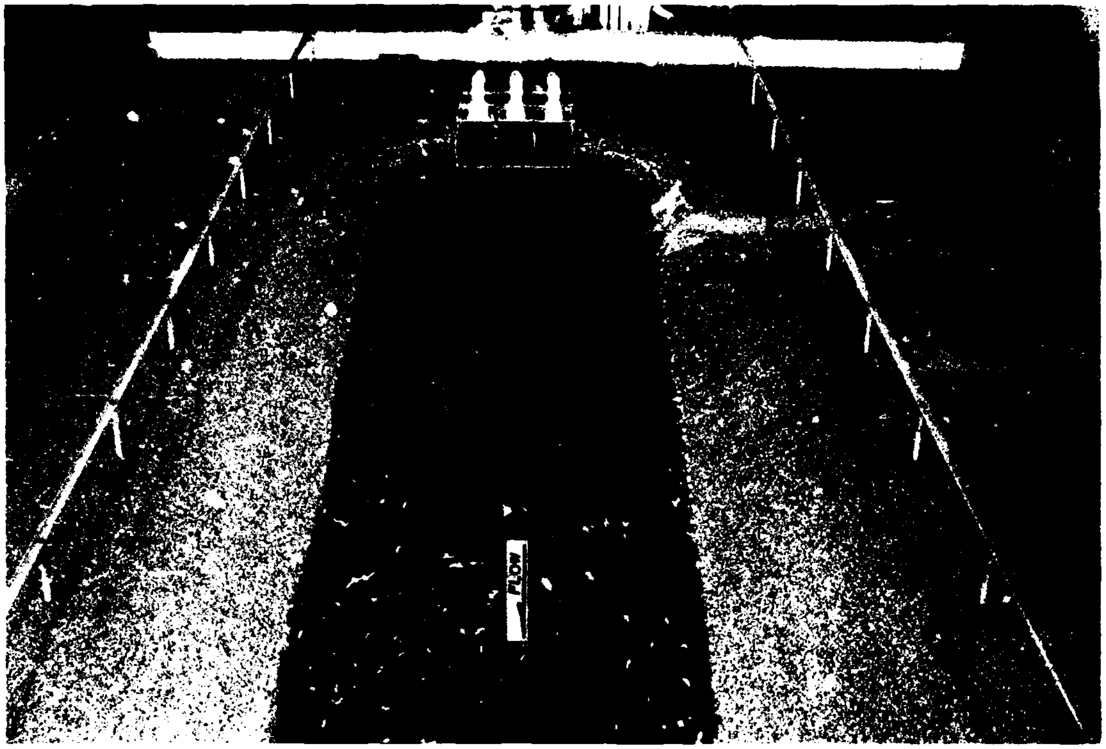


b. Downstream view

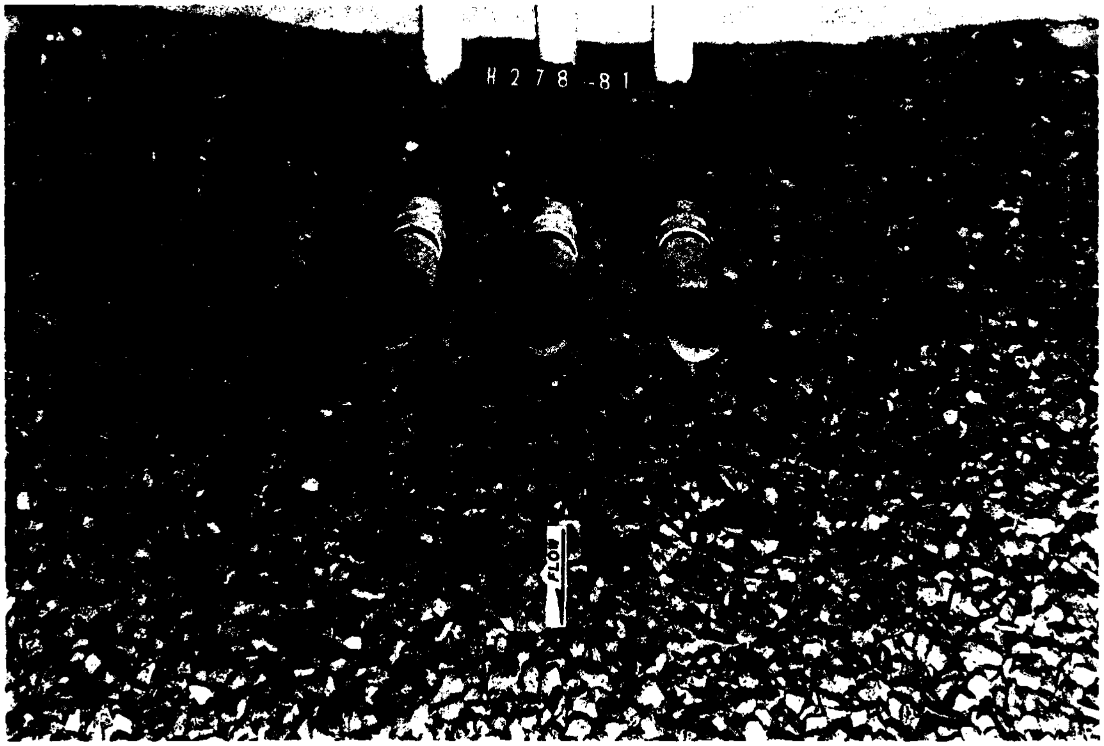


c. Discharge outlets

Figure 2. The 1:10-scale model of Cinque Hommes



a. Approach to sump



b. Discharge outlets

Figure 3. The 1:10-scale model of Bois Brule

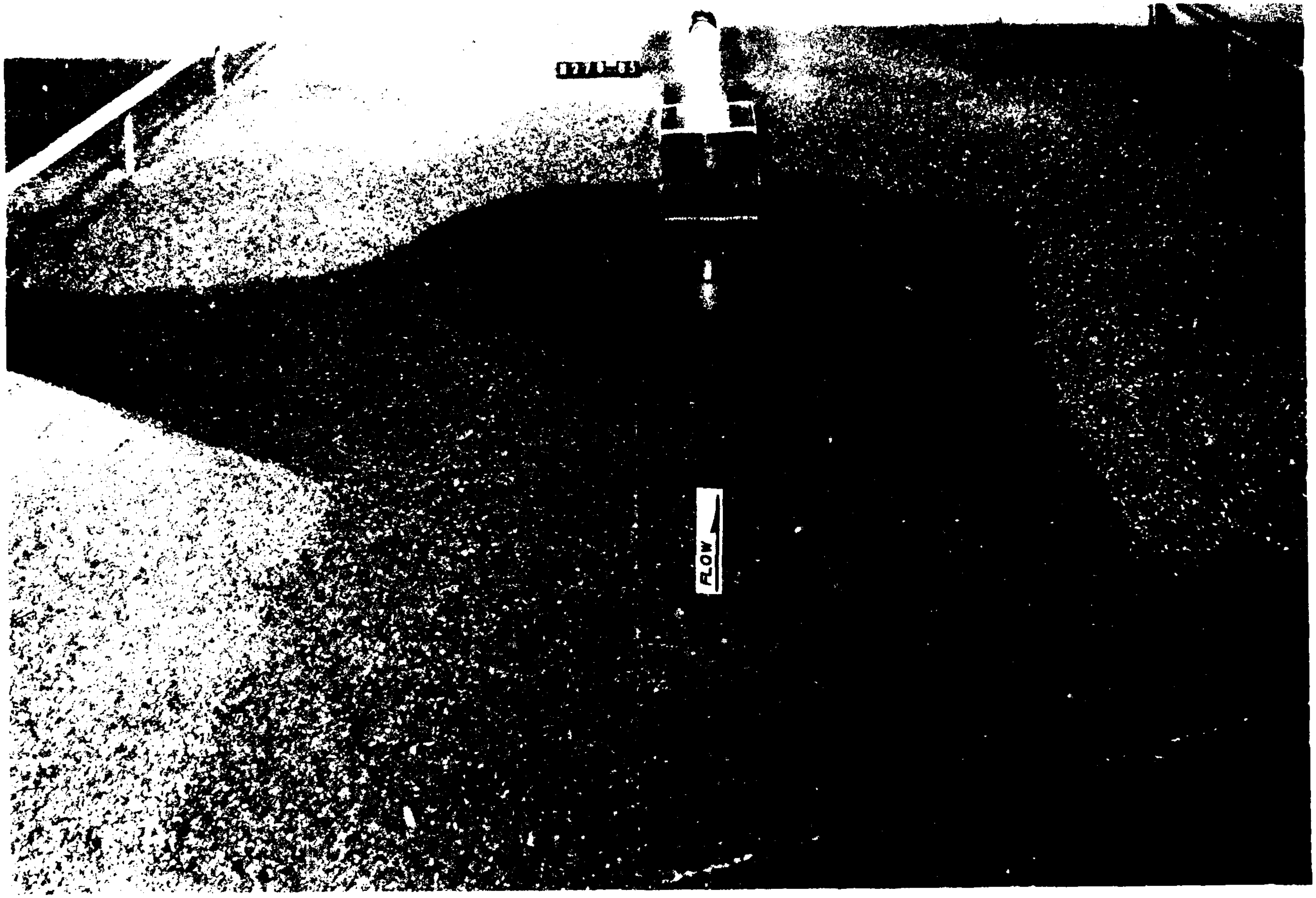


Figure 4. The 1:10-scale model of Missouri Chute

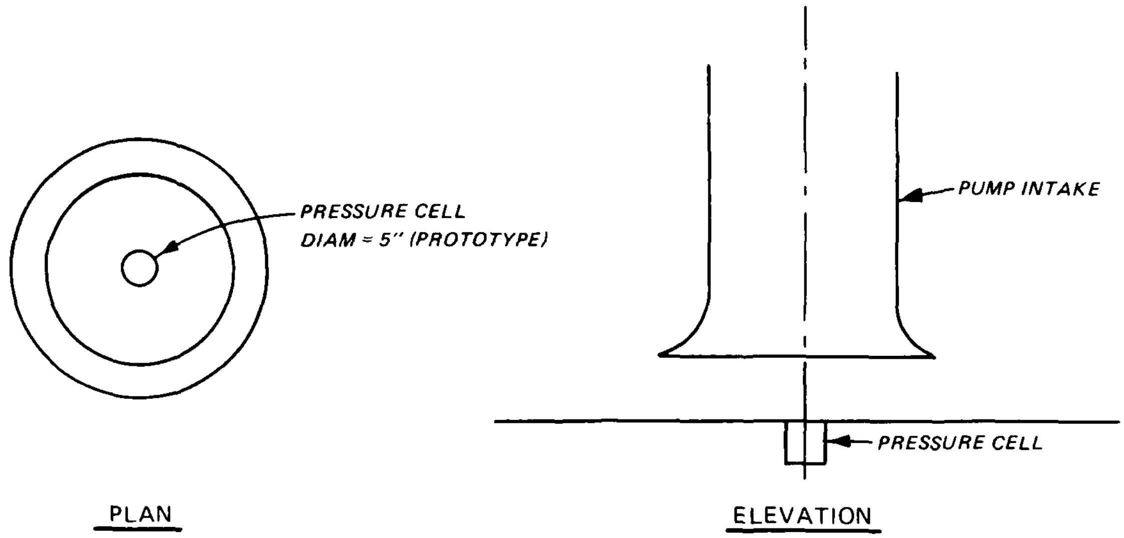


Figure 5. Pressure cell location

Figure 6. Vortimeter and pressure cell

n = revolutions per minute of the vortimeter

V_a = average suction column axial velocity, cfs, calculated by Q/A

Q = pump discharge, cfs

A = cross-sectional area of suction column, ft^2

The swirl angle is the speed of revolution of the vortimeter and has the advantage of having the same value in the model and prototype. A swirl angle greater than 3 deg is considered unacceptable. Surface vortices were evaluated by dye injection and visual observations. The stages of vortex development are indexed relative to the stages shown in Figure 7. A Stage C vortex is considered unacceptable.

6. The adequacy of proposed channel protection (riprap) at the discharge outlets was evaluated by simulating and investigating various sizes of riprap having a unit weight of 165 pcf.

Scale Relations

7. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations expressed in terms of the model scale or length ratio, L_r, are tabulated below:

Dimension*	Ratio	Scale Relations
Length	L_r	1:10
Area	$A_r = L_r^2$	1:100
Velocity	$V_r = L_r^{1/2}$	1:3.16
Discharge	$Q_r = L_r^{5/2}$	1:316.23
Time	$T_r = L_r^{1/2}$	1:3.16
Pressure	$P_r = L_r$	1:10
Frequency	$F_r = 1/L_r^{1/2}$	1:0.316

* Dimensions are in terms of length.

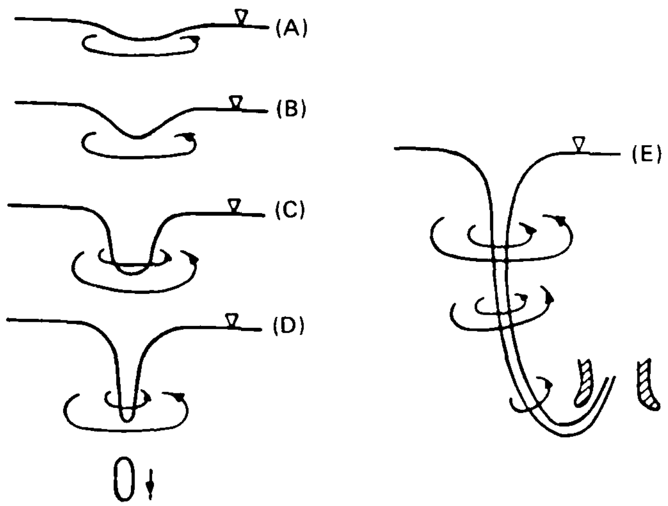


Figure 7. Stages in development of
air-entraining vortex

Measurement of discharge, water-surface elevations, heads, velocities, pressure, and frequency can be transferred quantitatively from the model to prototype equivalents by means of the scale relations.

PART III: TESTS AND RESULTS

Sumps

Cinque Hommes

8. The 1:10-scale reproduction of the original design (type 1) including the two 62.5-cfs pump intakes, operating platform, and the trashrack is shown in Figure 2. Surface currents (indicated by confetti) observed with the type 1 design for various flow conditions are shown in Photo 1. The magnitude and direction of bottom currents measured in the approach for the minimum water-surface elevation with one and two pumps operating, are shown in Plates 6 and 7, respectively. Flows in the approach to the sump were satisfactory for either or both pumps operating for all anticipated water-surface elevations. The presence of the trashrack did not adversely affect hydraulic flow characteristics of flow approaching the pump intakes. Flow in the sump was unsatisfactory. With two pumps operating, the geometry of the sump and the structure (supports for this operating platform) permitted counter eddies on opposite sides of the sump (Photos 1 and 2, Plate 7) and with one pump operating, an eddy developed on the side of the sump opposite from the pump operating (Plate 6). These eddies and local effects contributed to adverse flow conditions including surface vortices near the pump columns, flow instability, and severe swirl in the pump intake. Pressure fluctuations expressed as feet of water, swirl measured with vortimeters as revolutions per minute, and vortex tendencies are tabulated in Table 1.

9. Various sump designs were investigated to develop an intake configuration that provided uniform flow with a minimum of vortices, pressure fluctuations, and pre-rotation of flow at the pump intakes. The original design (type 1) was modified by adding various types of walls between or extending out from the platform support columns. Plan view sketches of the various sump designs investigated are shown in Plate 8. The hydraulic performance associated with each design is tabulated in Table 1. Types 1-6 did not provide any significant improvements in the hydraulic performance. Type 7 provided a significant improvement as shown in Table 1. Types 8 and 9 performed satisfactorily with both pumps operating. However, performance with single pump operation was unsatisfactory due to excessive pressure

fluctuations (Table 1) caused by flow separation around the upstream nose of the divider wall.

10. The type 7 sump (Plate 9) was the recommended design. Surface and bottom currents are indicated in Photos 3 and 4 and Plates 9 and 10, respectively. The wing walls reduced the magnitude of the currents circulating on the downstream side of the pump intakes (Plates 9 and 10, Photo 3a) and provided a stable hydraulic condition with less tendency for surface vortices, pressure fluctuations, and swirl at the pump intakes (Table 1).

Jones Cutoff

11. The geometry of the approach channel and sump and pumping conditions for the Jones Cutoff sump (Plate 2) were basically identical to those for the Cinque Hommes sump (Plate 1). The magnitude and direction of bottom currents measured in the approach to the original (type 1) design are shown in Plate 11. Adverse hydraulic conditions similar to those in the original Cinque Hommes design were observed (Table 2). The original design (type 1) was modified to the type 2 design by adding wing walls as shown in Plate 12. The wing walls of the type 2 design reduced the magnitude of the currents on the downstream side of the pump intakes (Plate 13) and provided a more stable hydraulic condition with less tendency for surface vortices, pressure fluctuations, and swirl at the pump intake (Table 2). The stages of vortex development tabulated in Table 2 are indexed relative to the stages shown in Figure 7.

12. Additional tests were conducted to evaluate the hydraulic feasibility of the type 3 sump which consisted of relocating the trashrack directly in front of the pump intake structure and enclosing the rear and sides with solid walls (Plate 14). Tests indicated that a divider (type 4 sump) between the pumps that extended from the rear wall upstream to the trashrack was needed to prevent adverse flows in the sump when one or both pumps were operating. The magnitude and direction of bottom currents are shown in Plate 15. Observations revealed flow separation at the upstream end of the sidewalls. However, this condition was minimized by the head loss and flow straightening provided by the trashrack. Hydraulic performance is indicated in Table 3.

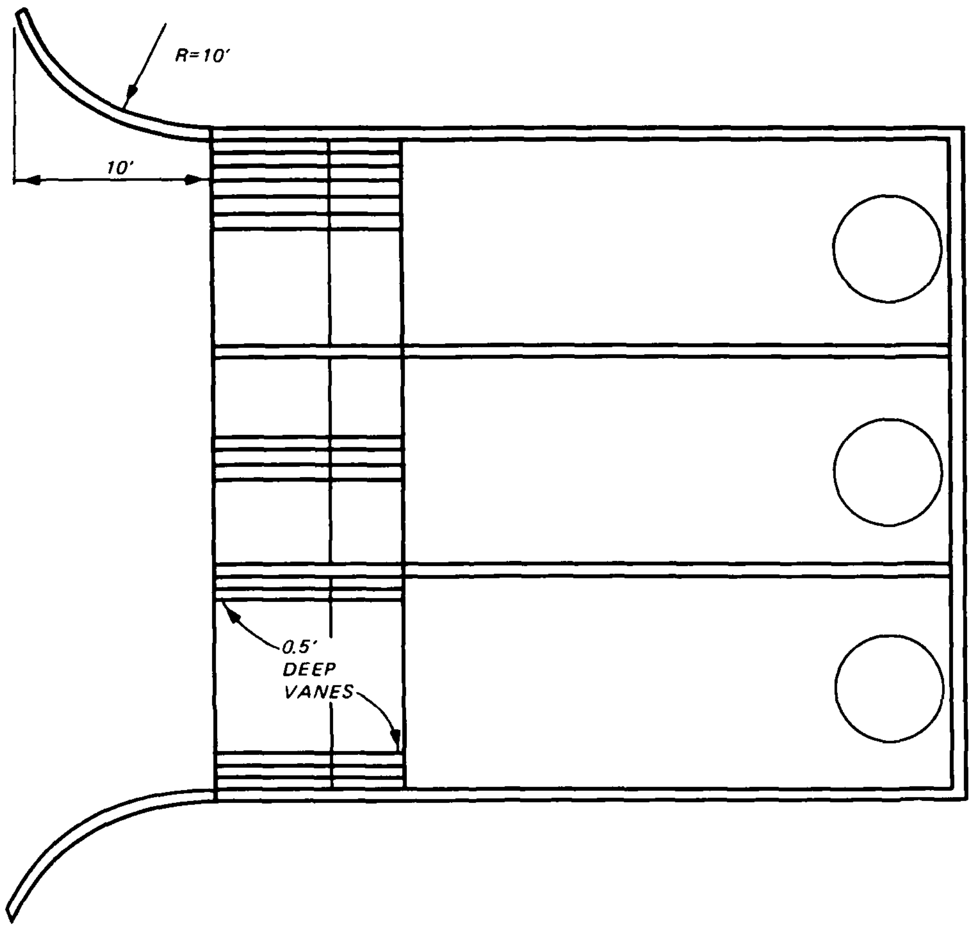
13. Results of the model tests of the Jones Cutoff pumping station indicated that either the type 2 (Plate 13) or type 4 (Plate 15) sump should

provide satisfactory hydraulic performance with either one or two pumps operating at anticipated water-surface elevations.

Bois Brule

14. Following model studies of the sumps for the Cinque Hommes and Jones Cutoff pumping stations, engineers from the St. Louis District decided to modify the trashrack and sump designs due to the high cost of building and maintaining the timber trashrack. Evaluation of a more classical trashrack and sump design with free-standing side and rear walls was initiated with the Bois Brule station (Figure 8).

15. The type 1 sump with the type 1 trashrack (Plate 16) provided satisfactory hydraulic performance for anticipated water-surface elevations. As the water-surface elevation in the sump was lowered below the minimum



NOTE: R = radius of curve

Figure 8. Bois Brule, type 1 sump, type 1 trashrack, type 1 training walls

anticipated (el 358.0),* hydraulic performance deteriorated (Table 4). Pressure fluctuations expressed in feet of water, swirl measured with vortimeters as degrees and observed vortex tendencies are tabulated in Table 4. The type 1 sump permitted minor flow separation at the upstream ends of the abutments and divider walls as shown in Plate 16. The trashrack was removed to permit an evaluation and comparison of flow conditions with and without the trashrack. Removal of the trashrack increased slightly the magnitude of the flow contractions which is reflected by the data tabulated in Table 4. Various flow conditions without the trashrack are shown in Photos 5 and 6. Pumps are numbered as shown in Photo 5. It was surmised that the 0.5-ft-deep vanes in the trashrack tended to improve flow conditions slightly by straightening and distributing flow. In an attempt to further improve hydraulic performance, wing walls were added to the abutments (Plate 16). The wing walls reduced the flow separation but provided negligible improvement in the flow at the pump intake (Table 4). It was decided that wing walls should not be added to the structure. The depth of the vanes of the type 1 trashrack was reduced from 0.5 to 0.33 ft (type 2 trashrack, Plates 17 and 18). There were only minor differences in the hydraulic characteristics of the two trashracks (Table 4).

16. Openings in the sump divider walls (type 2 sump) to permit passage of personnel were simulated in the model (Plate 17). The openings, located 2 ft from the edge of the bell, permitted a severe flow contraction as flow passed from a non-operating pump chamber to an operating pump chamber. The severe flow contraction caused uneven flow distribution, swirl in the pump intake, pressure fluctuations below the pump intake, and air-entraining surface vortices (Table 4). The passageway was moved upstream (type 3 sump) as shown in Plate 19 and the adverse hydraulic effects were reduced (Table 4). Evaluation of the type 3 sump without a trashrack indicated no significant change in the hydraulic characteristics (Table 4).

17. The recommended design (type 4 sump and type 2 trashrack) was obtained by moving the passageway as far upstream as structurally possible and reducing its size from 3.5 to 2.5 ft wide and from 7.0 to 5.5 ft high (Plate 20). The hydraulic characteristics obtained with the recommended sump

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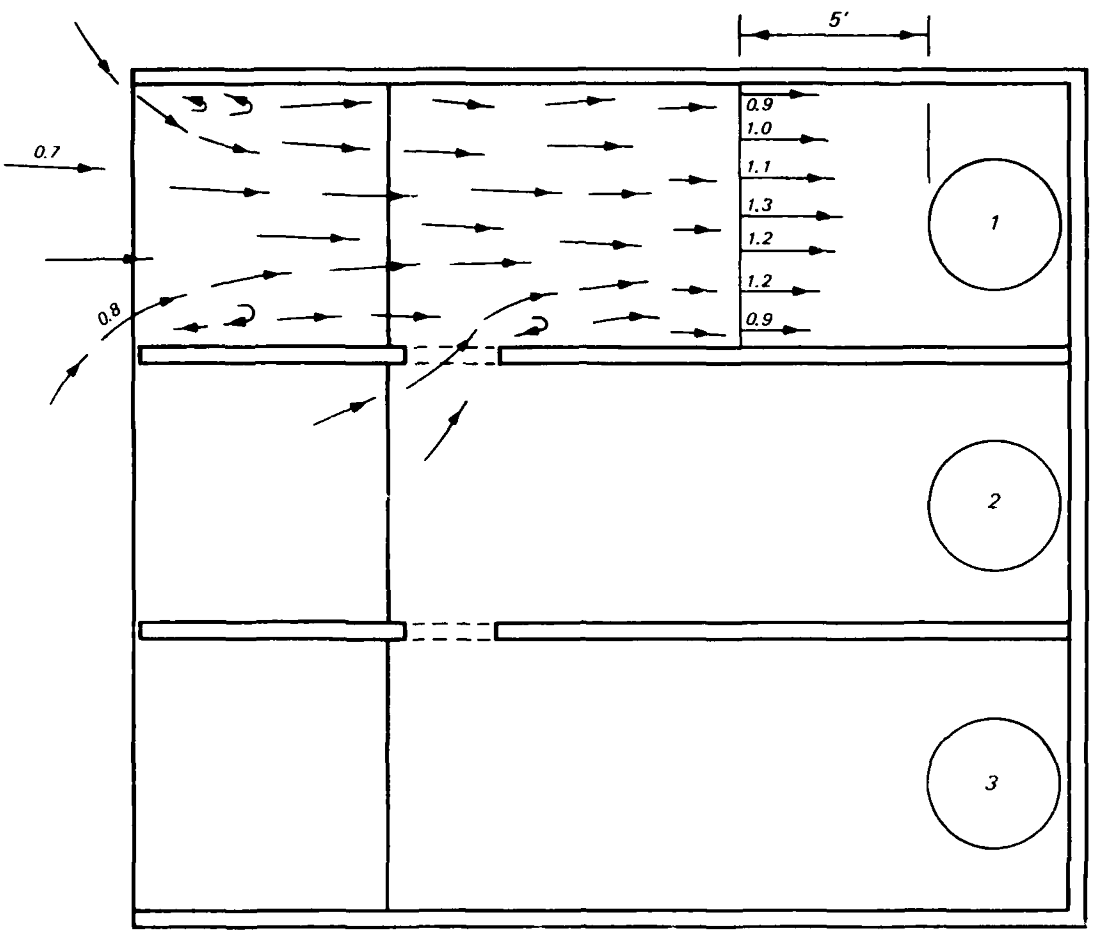
* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

design are shown in Table 4. Bottom velocities for various flow conditions are shown in Plate 21. Various approach flow conditions are shown in Photos 7 and 8. Surface currents are indicated by white streaks obtained from time exposures of confetti. Photos 9 and 10 indicate various flow conditions in the approach channel with the maximum anticipated flow of 5 cfs from the side inflow channel. Tests indicated that flow entering from the side channel had no significant effect on flow characteristics at the pump intakes. Flow conditions entering the pump sump are shown in Photo 11. Bottom currents are indicated by dye. Flow distribution inside the first pump bay with one pump operating is shown in Figure 9. Tests indicated negligible differences in the



NOTE DISCHARGE - 72 CFS

ALL VELOCITIES ARE IN PHOTOTYPE FT PER SECOND MEASURED 1 FT ABOVE THE BOTTOM.

PUMP 1 OPERATING

SUMP EL 358.0

Figure 9. Bois Brule, type 4 sump, type 2 trashrack

hydraulic flow characteristics with or without the trashrack (Table 4).

18. Results of model tests of the Bois Brule pump sump indicate that both the original (type 1 sump and type 1 trashrack) and recommended (type 4 sump and type 2 trashrack) designs provided satisfactory hydraulic performance for all anticipated flow conditions. However, the type 4 sump and type 2 trashrack were recommended due to the need for personnel passageways through the sump divider walls.

Missouri Chute

19. The Missouri Chute pumping station (Figure 10, Plate 4) is designed for a single pump to convey a maximum discharge of 50 cfs. This rate of flow may be contributed by the main approach channel, or it may be provided from a combination of flows with as much as 20 cfs from the side channel and 30 cfs from the main channel.

20. Hydraulic performance with all of the flow from the main channel was satisfactory for all anticipated water-surface elevations, from a minimum elevation of 354.0 to a maximum of 358.0. Flow entered the sump with only minor symmetrical contractions of flow at each abutment and was distributed evenly as it approached the pump intake. Flow conditions are shown in

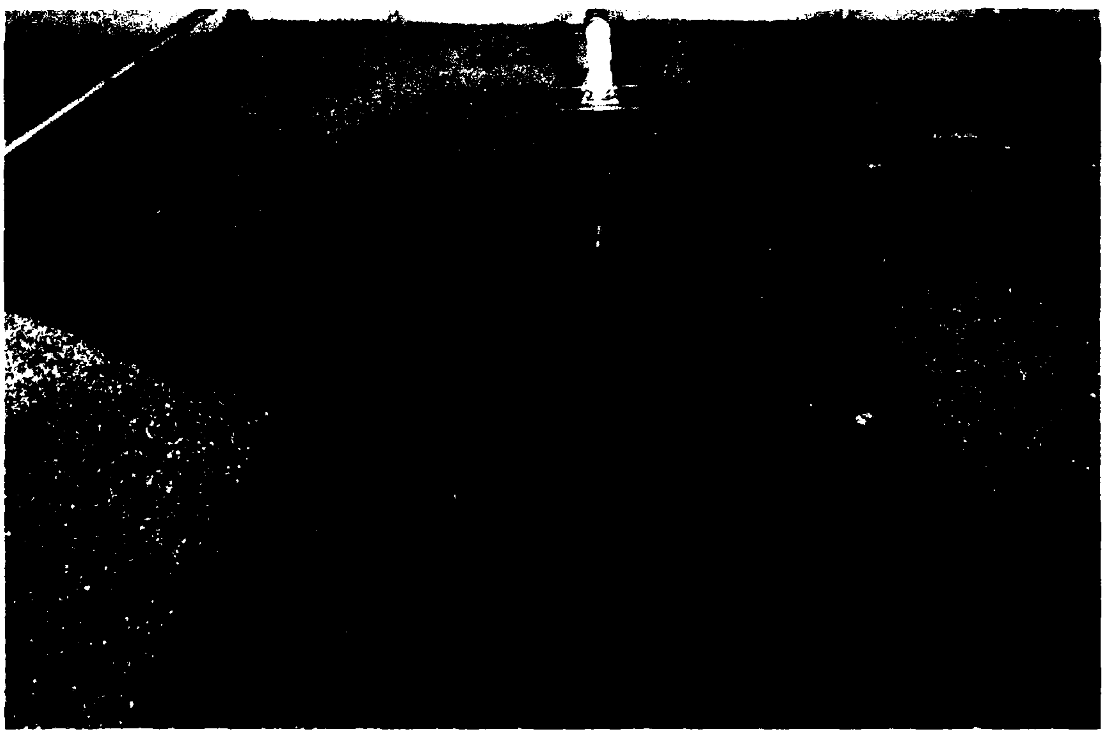


Figure 10. Missouri Chute sump

Photo 12. All photographs depict the pumping station without the trashrack to facilitate visual observation of flow in the sump. Removal of the trashrack did not significantly alter hydraulic performance of the sump. Magnitudes and directions of currents measured 1 ft above the bottom of the approach are shown in Plate 22.

21. Hydraulic performance was evaluated with a combination of flow consisting of 30 cfs from the main channel and 20 cfs from the side channel. Observations and tests indicated that the side channel flow caused unstable flow conditions in the main approach, flow entering the sump distributed unevenly and severe flow contraction at either sump abutment depended on the current direction. Various flow conditions are shown in Photo 13. Magnitudes and directions of currents measured 1 ft above the bottom of the approach channel are presented in Plate 23.

22. A comparison of indices for describing hydraulic performance with flow from only the main channel and in combination with the side channel is provided in Table 5. It is apparent from the data presented in Table 5 that flow from the side channel adversely affects flow conditions in the sump. Modifications such as streamlining approach geometry and providing divider walls to deter or eliminate circulation of flow in the approach did not improve hydraulic performance.

23. The invert of the side channel was lowered 7 ft to el 348.0 to form the type 2 design approach in an attempt to reduce the magnitude of the lateral currents entering the main channel. However, flow from the type 2 approach produced adverse hydraulic conditions in the sump.

24. The mouth of the side channel was then relocated 105 ft rather than 50 ft upstream of the center of the pump to form the type 3 approach design. Tests revealed that the adverse currents generated in the confluence of the two channels were dispersed as flow approached the sump. Hydraulic performance in the sump with flow in both channels was satisfactory with the type 3 approach and identical to that observed with the original approach and flow from only the main channel. To provide satisfactory sump performance, it is recommended that the mouth of the side channel be located 105 ft upstream from the center of the pump.

Outlets

25. The test procedure for evaluating riprap protection for the

1:10-scale models of the saxophone discharge outlets was similar for all tests. A typical 45-deg saxophone outlet is shown in Plate 24. A typical test for a given stone size consisted of a relative high tailwater elevation that prevented riprap failure while subjected to the maximum anticipated flow. The tailwater elevation was lowered every 2.5 hr (prototype) in increments of 1 ft to determine the maximum tailwater elevation that permitted rock displacement. This procedure was repeated for various saxophone outlet designs, rock sizes, and channel configurations. For all tests, the rock size is described by average diameter of the rock d_{50} and the riprap blanket thickness is equal to $2d_{50}$.

Cinque Hommes

26. The Cinque Hommes discharge outlet (Plate 1) consisted of two 45-deg, 30-in.-diam saxophone discharge outlets. The two 45-deg saxophone discharge outlets (type 1) are shown in Plates 24 and 25. Tests to determine riprap failure points were conducted with one and two pumps operating and various sizes of riprap. The basic data obtained from these tests and the best fit curves developed from the method of least squares are shown in Plate 26. Various flow conditions with one and two pumps operating are shown in Photos 14 and 15, respectively.

27. Tests were conducted to evaluate riprap protection with a 90-deg saxophone outlet (type 2 design). The basic data and curves are shown in Plate 27. A comparison of the data in Plate 26 with that in Plate 27 indicates the 90-deg outlet permits a reduction in tailwater elevation for a given riprap size. Various flow conditions are shown in Photos 16 and 17. Although the 90-deg saxophone outlets permitted a smaller riprap size for a given tailwater elevation, representatives from the St. Louis District preferred the 45-deg saxophone outlet due to less hydraulic thrust on the 45-deg outlets and outlet supports.

28. The excavated portion of the outlet channel (Plates 24 and 25) was filled to simulate an unexcavated channel and riprap was placed over the fill (type 3). Results of tests conducted with the 45-deg outlet to determine riprap stability are shown in Plate 28. A comparison of the curve in Plate 28 (unexcavated channel) with the curve in Plate 26 (excavated channel) indicated that the excavated channel permitted a significant reduction in stone size for similar hydraulic conditions.

Jones Cutoff

29. The Jones Cutoff discharge outlet consisted of two 45-deg, 36-in.-diam outlets (Plate 2). The geometry of the Jones Cutoff discharge outlets and exit channel are almost identical to the geometry modeled in the Cinque Hommes outlet except the Jones Cutoff outlet has 36-in.-diam outlets, and Cinque Hommes has 30-in.-diam outlets.

30. The tailwater conditions at which three sizes of stone failed with the 36-in.-diam outlets are shown in Plate 29. A comparison of Plate 29 with Plate 28 (30-in.-diam) indicated that the 36-in.-diam outlets permitted a reduction in stone size for similar hydraulic conditions. Various flow conditions and riprap failure are shown in Photo 18.

Bois Brule

31. The Bois Brule discharge outlet consisted of three 45-deg, 36-in.-diam saxophone discharge outlets (Plate 3). The tailwater conditions at which three sizes of stone failed are shown in Plate 30. Various flow conditions and riprap failure are shown in Photo 19.

Missouri Chute

32. The Missouri Chute discharge outlet consisted of one 36-in.-diam, 45-deg saxophone outlet (Plate 4). The tailwater conditions at which two sizes of stone failed are shown in Plate 31. Stone with an average diameter, d_{50} , of 17.5 in. was stable for all anticipated flow conditions. Conditions during and after a flow of 50 cfs are shown in Photo 20.

PART IV: DISCUSSION OF RESULTS

33. Hydraulic performance of the original design sump for Cinque Hommes was unsatisfactory due to flow passing by the two pump intakes and generating counter eddies on each side of the sump. These eddies contributed to the development of surface vortices, flow instability, and swirl in the pump intakes. The magnitude of the eddies was reduced and satisfactory performance, with one or two pumps operating, was obtained by extending a wing wall out from each side of the structure.

34. The approach channel, number of pumps, and sump design for Jones Cutoff pumping station were similar to the design for Cinque Hommes, and similar hydraulic performance was observed. The wing walls were effective in reducing the adverse flow performance. Satisfactory hydraulic performance was also obtained by moving the trashrack closer to the structure and enclosing the rear and sides of the sump.

35. Following the model studies of the sumps for Cinque Hommes and Jones Cutoff, engineers from the St. Louis District revised the design of the sump and trashrack for Bois Brule due to the high cost of building and maintaining the timber trashrack. The revised design (prior to model tests) for Bois Brule consisted of a classical trashrack and free-standing side and rear walls. The model indicated satisfactory hydraulic performance for all anticipated flow conditions and provided guidance for design of the passageways in the sump divider walls. Approach wing walls did not significantly improve hydraulic performance in the sump.

36. The model of the Missouri Chute sump indicated unsatisfactory flow conditions due to adverse currents in the sump generated by lateral flow from a side channel located normal to the main channel. Satisfactory flow conditions were obtained by relocating the mouth of the side channel upstream.

37. The designs of the 45-deg saxophone outlets and channel configurations for the four stations were similar. Test results provided guidance for determining hydraulic conditions that caused incipient riprap displacement for various bed protection designs. Tests indicated that the riprap was slightly more stable with a 90-deg outlet than with a 45-deg outlet. However, the 45-deg saxophone outlet was preferred by structural engineers due to less thrust on the outlet conduits and supports.

Table 1

Cinque Hommes Hydraulic Performance, Sump Types 1-9

Pump	Pumps Operating*	Design	Sump Water-Surface El, ft	Swirl Angle deg**	Fluctuating Pressure ft of water	Stages In Vortex Development†
1	1 and 2	Type 1	355.0	4.6→	1.4	B
2	1 and 2	Type 1	355.0	←5.7	1.8	B
1	1	Type 1	355.0	←7.4	1.8	B
1	1 and 2	Type 1	356.0	8.5→	1.6	B
2	1 and 2	Type 1	356.0	←8.0	1.7	B
1	1	Type 1	356.0	←5.1	1.4	B
1	1 and 2	Type 1	357.0	5.1→	0.7	B
2	1 and 2	Type 1	357.0	←5.1	0.5	B
1	1	Type 1	357.0	←4.6	1.1	B
1	1 and 2	Type 1	358.0	6.3→	0.7	B
2	1 and 2	Type 1	358.0	←5.7	0.6	B
1	1	Type 1	358.0	←5.1	0.6	B
1	1 and 2	Type 1	359.0	6.3→	0.9	B
2	1 and 2	Type 1	359.0	←5.1	0.7	B
1	1	Type 1	359.0	←2.9	0.6	B
1	1 and 2	Type 1	360.0	5.7→	0.5	B
2	1 and 2	Type 1	360.0	←4.6	0.5	B
1	1	Type 1	360.0	←2.9	0.4	B
1	1 and 2	Type 2	358.0	5.1→	0.6	B
2	1 and 2	Type 2	358.0	←5.7	0.6	B
1	1	Type 2	358.0	←5.1	0.6	B
1	1 and 2	Type 3	358.0	←11.3	3.0	D
2	1 and 2	Type 3	358.0	←14.0	3.5	D
1	1	Type 3	358.0	←14.0	3.5	D
1	1 and 2	Type 4	358.0	10.7→	0.7	B
2	1 and 2	Type 4	358.0	←5.1	0.6	B
1	1	Type 4	358.0	10.7→	0.6	B
1	1 and 2	Type 5	358.0	3.4→	0.5	B
2	1 and 2	Type 5	358.0	←5.1	0.5	B
1	1	Type 5	358.0	3.4→	0.5	B

(Continued)

Note: All magnitudes expressed in prototype equivalents.
* Discharge per pump = 62.5 cfs.
** → clockwise rotation; ← counterclockwise rotation.
† See Figure 7.

Table 1 (Concluded)

Pump	Pumps Operating	Design	Sump Water-Surface El, ft	Swirl Angle deg	Fluctuating Pressure ft of water	Stages In Vortex Development
1	1 and 2	Type 6	358.0	19.3→	23.0	B
2	1 and 2	Type 6	358.0	←20.8	25.0	B
1	1	Type 6	358.0	21.3→	25.0	B
1	1 and 2	Type 7	355.0		0.5	B
2	1 and 2	Type 7	355.0	2.3→	0.5	B
1	1	Type 7	355.0	←2.3	0.5	B
1	1 and 2	Type 7	356.0	←1.7	0.3	B
2	1 and 2	Type 7	356.0	2.3→	0.4	B
1	1	Type 7	356.0	←2.3	0.3	B
1	1 and 2	Type 7	357.0	←1.7	0.3	A
2	1 and 2	Type 7	357.0	1.7→	0.3	A
1	1	Type 7	357.0	←2.3	0.3	A
1	1 and 2	Type 7	358.0	←1.7	0.2	A
2	1 and 2	Type 7	358.0	1.2→	0.2	A
1	1	Type 7	358.0	←1.7	0.2	A
1	1 and 2	Type 7	359.0	←1.7	0.2	A
2	1 and 2	Type 7	359.0	0.6→	0.1	A
1	1	Type 7	359.0	←1.2	0.2	A
1	1 and 2	Type 7	360.0	←1.2	0.1	A
2	1 and 2	Type 7	360.0	0.6→	0.1	A
1	1	Type 7	360.0	←0.6	0.1	A
1	1 and 2	Type 7	361.0	←0.6	0.1	A
2	1 and 2	Type 7	361.0	0.6→	0.1	A
1	1	Type 7	361.0	←0.6	0.1	A
1	1 and 2	Type 7	362.0	←0.6	0.1	A
2	1 and 2	Type 7	362.0	0.6→	0.1	A
1	1	Type 7	362.0	←0.6	0.1	A
1	1 and 2	Type 8	358.0	←0.6	0.2	A
2	1 and 2	Type 8	358.0	0.6→	0.2	A
1	1	Type 8	358.0	1.7→	0.9	C
1	1 and 2	Type 9	358.0	←0.6	0.2	A
2	1 and 2	Type 9	358.0	0.6→	0.2	A
1	1	Type 9	358.0	2.3→	1.3	C

Table 2

Jones Cutoff Hydraulic Performance, Sump Types 1 and 2

			Design Type 1			Design Type 2		
Pump	Pumps Operating*	Sump Water-Surface El, ft	Swirl Angle, deg**	Pressure Fluctuations feet of water	Stages in Vortex Development**	Swirl Angle, deg**	Pressure Fluctuations ft of water	Stages in Vortex Development†
1	1 and 2	348.0	14.0→	1.6	B	←8.6	0.5	B
2	1 and 2	348.0	←8.0	1.4	B	5.7→	0.5	B
1	1	348.0	←5.7	1.2	B	←0.9	0.4	B
1	1 and 2	350.0	9.7→	1.3	B	←5.7	0.4	A
2	1 and 2	350.0	←7.7	1.5	B	7.7→	0.4	A
1	1	350.0	←1.7	1.1	B	←0.9	0.4	A
1	1 and 2	352.0	7.7→	1.2	B	←1.7	0.3	A
2	1 and 2	352.0	←8.0	1.3	B	1.8→	0.2	A
1	1	352.0	←1.7	1.0	B	←0.9	0.3	A
1	1 and 2	354.0	7.7→	1.0	B	←1.8	0.2	A
2	1 and 2	354.0	←4.9	1.0	B	1.8→	0.2	A
1	1	354.0	←0.9	1.0	B	0	0.2	A
1	1 and 2	356.0	8.0→	1.0	B	←1.7	0.1	A
2	1 and 2	356.0	←8.0	0.9	B	1.7→	0.1	A
1	1	356.0	←0.9	0.7	B	0	0.1	A
1	1 and 2	358.0	7.7→	0.7	B	←1.7	0.1	A
2	1 and 2	358.0	←7.7	0.7	B	1.7→	0.1	A
1	1	358.0	←0.9	0.4	B	0	0.1	A

Note: All magnitudes are expressed in prototype equivalents.

* Discharge per pump = 62.5 cfs.

** → clockwise rotation; ← counterclockwise rotation.

† See Figure 7.

Table 3

Jones Cutoff Hydraulic Performance, Type 4 Sump

Pump	Pumps Operating*	Sump Water-Surface El, ft	Swirl Angle, deg**	Fluctuations feet of water	Stage In Vortex Development†
1	1 and 2	348.0	←8.6	0.8	B
2	1 and 2	348.0	9.7→	0.8	B
1	1	348.0	4.6→	0.6	B
1	1 and 2	350.0	←4.6	0.6	B
2	1 and 2	350.0	5.7→	0.5	B
1	1	350.0	4.0→	0.4	B
1	1 and 2	352.0	←4.0	0.5	A
2	1 and 2	352.0	1.9→	0.5	A
1	1	352.0	0.8→	0.3	A
1	1 and 2	354.0	1.9→	0.4	A
2	1 and 2	354.0	0.8→	0.3	A
1	1	354.0	0.8→	0.2	A
1	1 and 2	356.0	←1.9	0.2	A
2	1 and 2	356.0	1.9→	0.2	A
1	1	356.0	0.8→	0.2	A
1	1 and 2	358.0	←0.8	0.1	A
2	1 and 2	358.0	0.8→	0.1	A
1	1	358.0	0.8→	0.1	A

Note: All magnitudes are expressed in prototype equivalents.

* Discharge per pump = 62.5 cfs.

** → Clockwise rotation; ← Counterclockwise rotation.

† See Figure 7.

Table 4

Bois Brule Hydraulic Sump Performance

Pump	Pumps Operating*	Sump Water-Surface El, ft	Swirl Angle, deg**	Pressure Fluctuations ft of water	Stages in Vortex Development†
			Type 1 Sump, Type 1 Trashrack		
1	1	356.0	7.4→	3.0	E
1	1	358.0	1.7→	1.0	B
1	1 and 2	↓	←2.3	1.5	↓
2	1 and 2	↓	2.3→	1.5	↓
2	2	↓	1.7→	1.0	↓
3	3	↓	←1.7	1.0	↓
1	1 and 3	↓	←0.8	1.0	↓
3	1 and 3	↓	2.3→	1.0	↓
1	All	↓	←2.3	1.0	↓
2	All	↓	←1.7	0.5	↓
3	All	↓	2.3→	1.0	↓
1	1	360.0	1.7→	1.0	A
1	1 and 2	↓	←2.3	1.5	↓
2	1 and 2	↓	2.3→	1.5	↓
2	2	↓	0.8→	0.5	↓
3	3	↓	←1.7	1.0	↓
1	1 and 3	↓	0.8→	1.0	↓
3	1 and 3	↓	←2.3	1.0	↓
1	All	↓	←2.3	1.0	↓
2	All	↓	0	0.5	↓
3	All	↓	1.7→	1.0	↓
			Type 1 Sump, No Trashrack		
2	2	358.0	1.7→	1.0	B
1	1 and 2	358.0	←2.3	1.5	↓
2	1 and 2	358.0	3.4→	3.0	↓
1	All	360.0	←2.3	1.5	↓
2	All	360.0	←1.7	1.0	↓
3	All	360.0	2.3→	1.0	↓
			Type 1 Sump, Type 1 Trashrack, Type 1 Training Walls		
1	1	358.0	1.7→	1.0	B
3	3	358.0	←1.7	1.0	↓
1	1 and 3	358.0	1.7→	1.0	↓

(Continued)

Note: All magnitudes are expressed in prototype equivalents.
* Discharge per pump = 72 cfs.
** → clockwise rotation; ← counterclockwise rotation.
† See Figure 7.

Table 4 (Continued)

Pump	Pumps Operating	Sump Water-Surface El, ft	Swirl Angle, deg	Pressure Fluctuations ft of water	Stages in Vortex Development
		Type 1 Sump, Type 1 Trashrack, Type 1 Training Walls (Continued)			
3	1 and 3	358.0	←1.7	1.0	B
1	1	360.0	←0.8	0.5	A
3	3	360.0	←0.8	0.5	A
1	1 and 3	360.0	0.8→	0.5	A
3	1 and 3	360.0	←1.7	0.5	A
		Type 1 Sump, Type 2 Trashrack			
1	1	358.0	1.7→	1.0	B
2	2	↓	←1.7	1.0	↓
1	All	↓	←2.3	1.0	↓
2	All	↓	←2.3	1.0	↓
3	All	↓	2.3→	1.0	↓
1	1	360.0	0.8→	1.0	A
2	2	↓	0.8→	1.0	↓
1	All	↓	←0.8	1.0	↓
2	All	↓	0	1.0	↓
3	All	↓	0.8→	1.0	↓
		Type 2 Sump, Type 1 Trashrack			
3	3	358.0	←8.5	4.0	D
3	3	360.0	←6.8	3.0	D
		Type 3 Sump, Type 1 Trashrack			
3	3	358.0	←5.0	2.0	C
3	3	360.0	←3.4	1.0	C
		Type 3 Sump, No Trashrack			
1	1	358.0	5.0→	2.0	C
2	2	358.0	4.2→	1.0	C
1	1	360.0	3.4→	3.0	B
2	2	360.0	3.4→	0.5	B
		Type 4 Sump, Type 2 Trashrack			
1	1	358.0	2.5→	1.0	B
2	2	↓	2.5→	1.0	↓
1	All	↓	2.5→	1.0	↓

(Continued)

Table 4 (Concluded)

Pump	Pumps Operating	Sump Water-Surface El, ft	Swirl Angle, deg	Pressure Fluctuations ft of water	Stages in Vortex Development
		Type 4 Sump, No Trashrack			
2	All	358.0	←1.7	1.0	B
3	All		←1.7	1.0	
1	1	360.0	1.7→	1.0	
2	2		1.7→	1.0	
1	All		1.7→	1.0	
2	All		←1.7	1.5	
3	All		←1.7	1.5	
1	1	358.0	2.5→	1.0	
2	2		2.5→	1.0	
1	All		←2.5	1.5	
2	All		1.7→	1.0	
3	All		1.7→	1.0	
1	1	360.0	2.5→	1.5	
2	2		1.7→	1.5	
1	All		←2.5	1.5	
2	All		←1.7	1.0	
3	All		1.7→	1.5	

(Sheet 3 of 3)

Table 5

Missouri Chute Hydraulic Performance, Type 1 Sump

Pump*	Side Channel Discharge cfs**	Sump Water-Surface El, ft	Swirl Angle, deg†	Pressure Fluctuation ft of water	Stages in Vortex Development††
1	0	354.0	2.2→	2	B
1	0	356.0	0.6→	1	A
1	0	358.0	0	1	A
1	20	354.0	4.4→	3	C
1	20	356.0	4.4→	3	C
1	20	358.0	0.6→	2	B

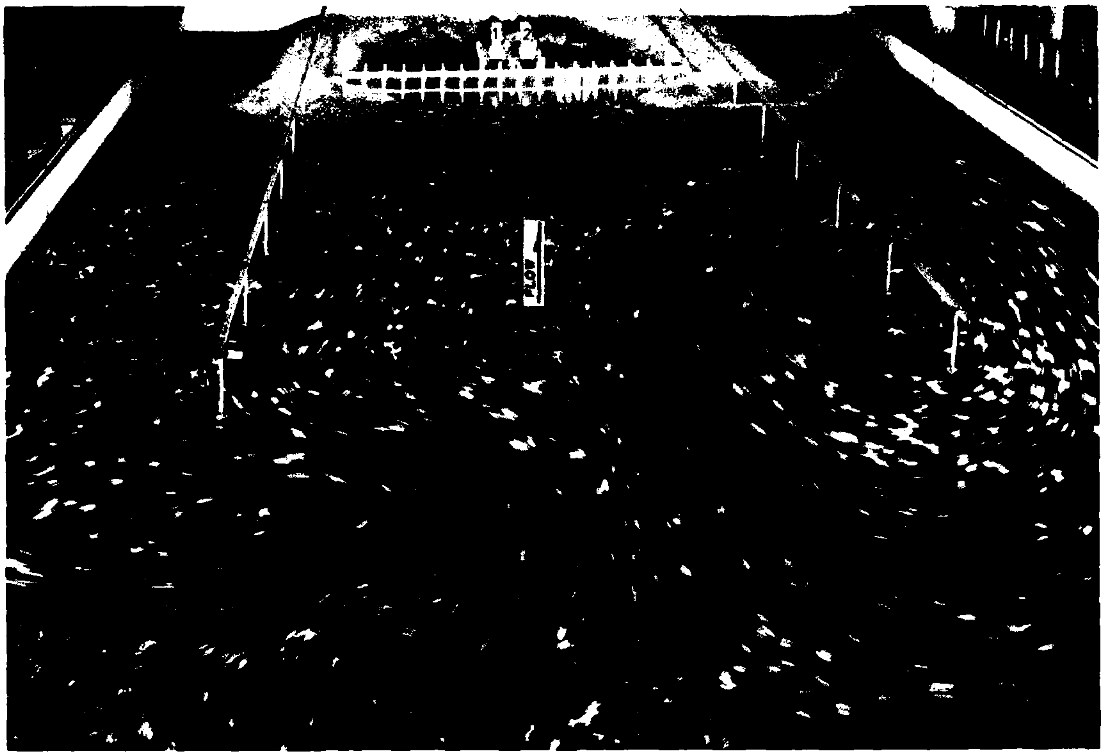
Note: All magnitudes expressed in prototype equivalents.

* Discharge per pump = 50 cfs.

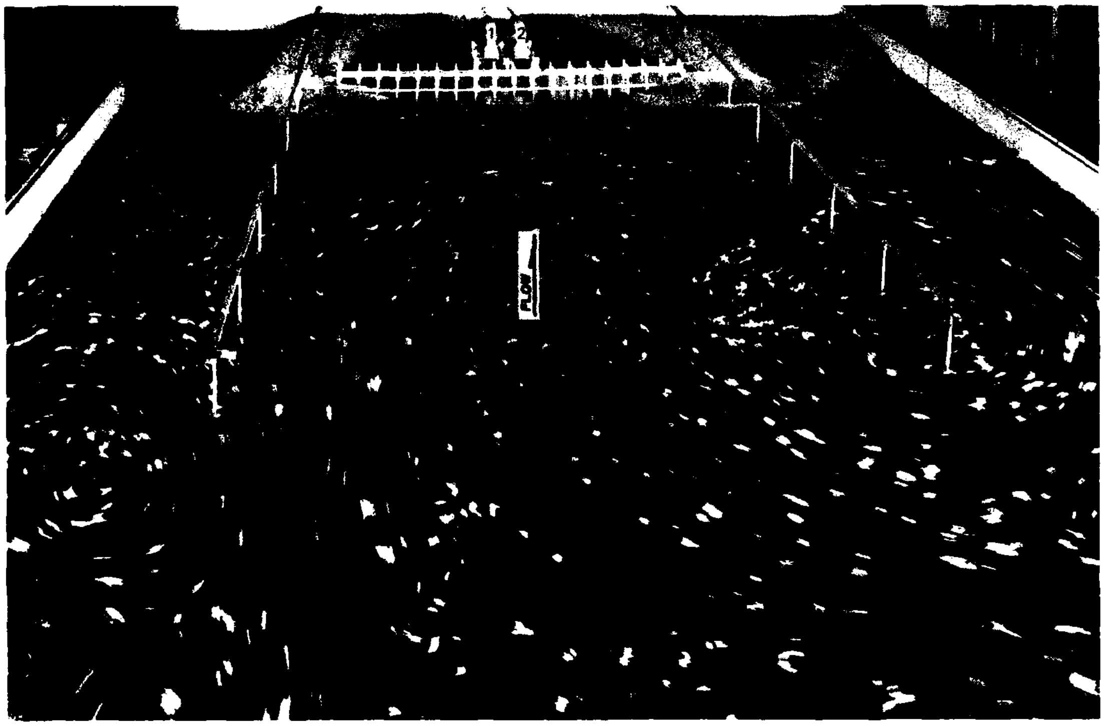
** See Photo 13.

† → clockwise rotation; ← counterclockwise rotation.

†† See Figure 7.

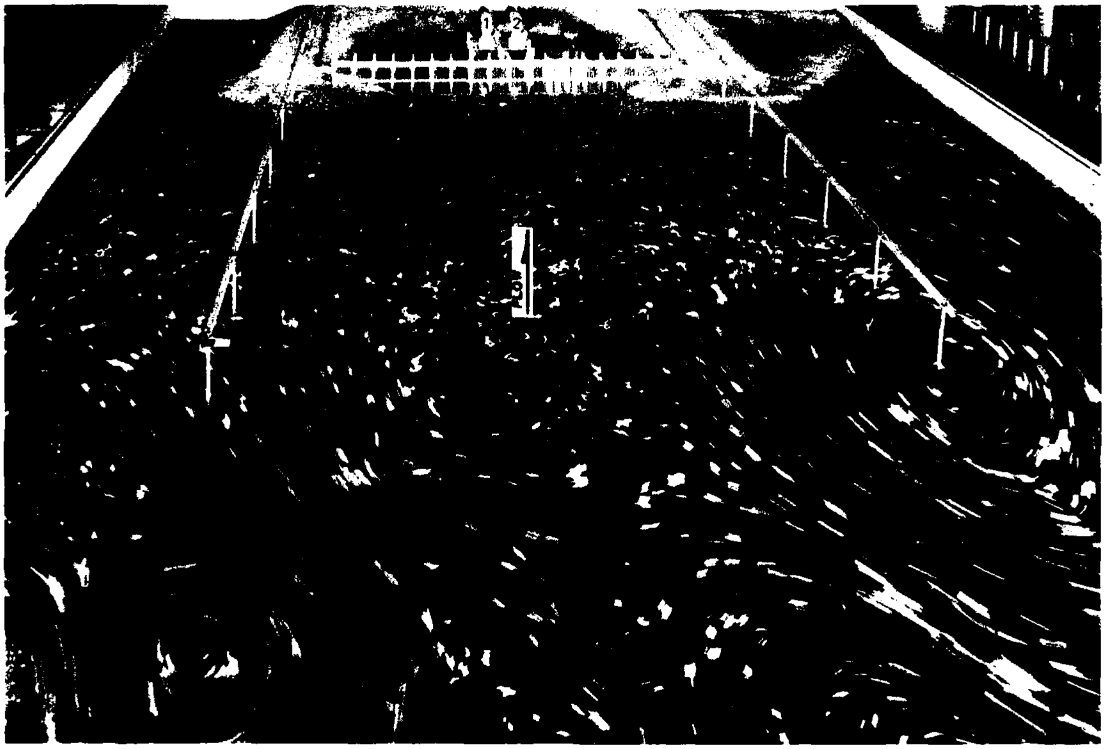


a. Pump 1 operating



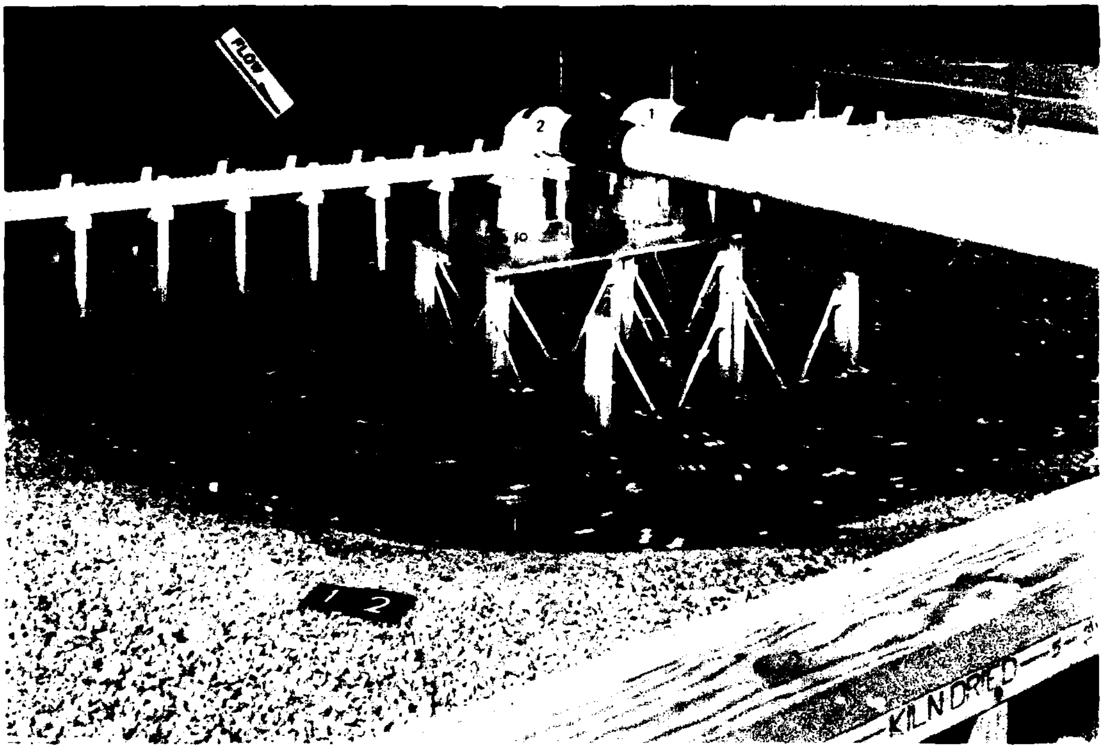
b. Pump 2 operating

Photo 1. Cinque Hommes, approach surface flow patterns, type 1 sump, discharge per pump 62.5 cfs, water-surface el 358.0, time exposure 33 sec (prototype) (Continued)

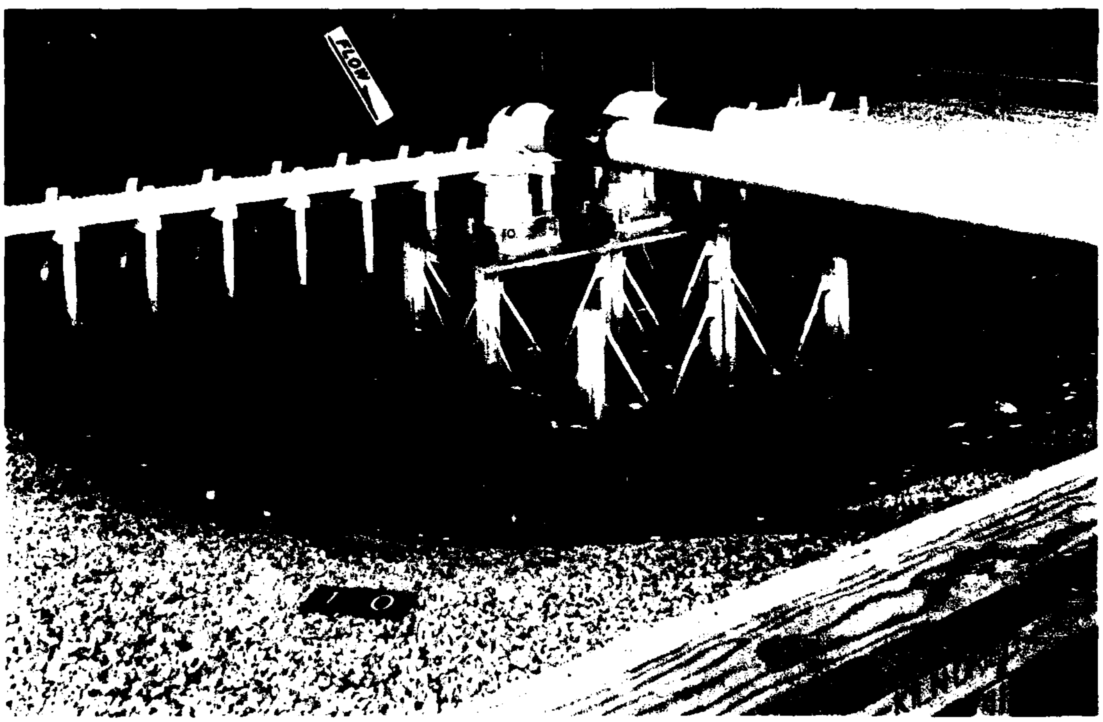


c. Pumps 1 and 2 operating

Photo 1. (Concluded)

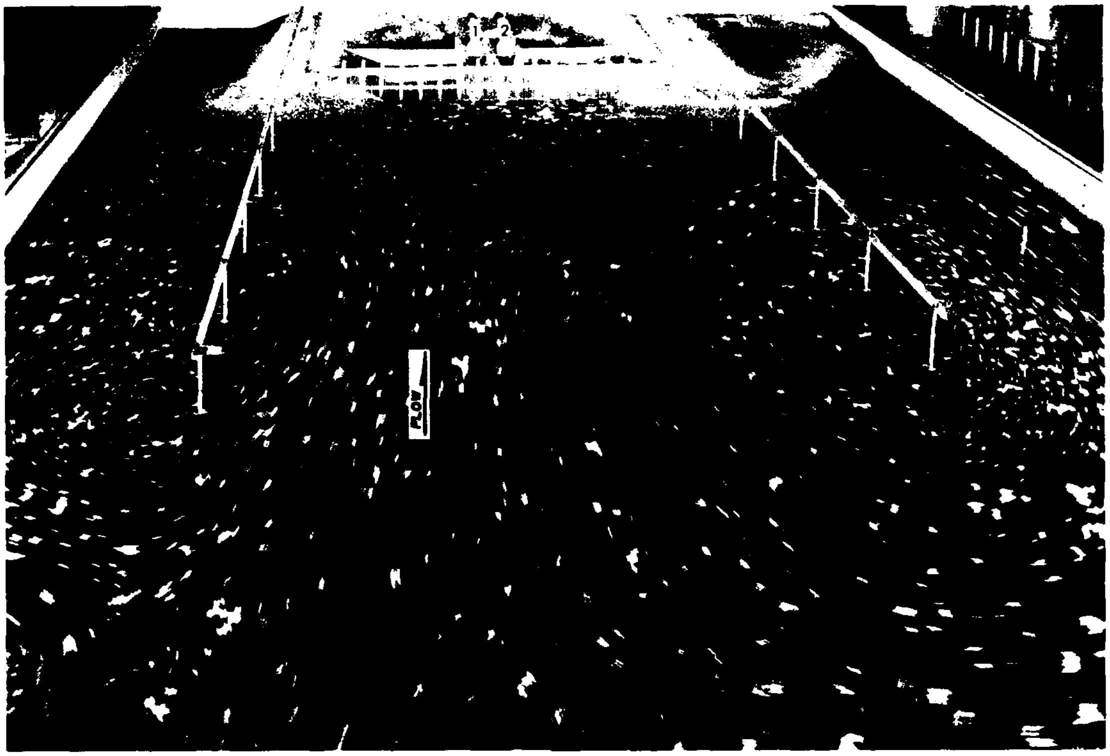


a. Pump 2 operating

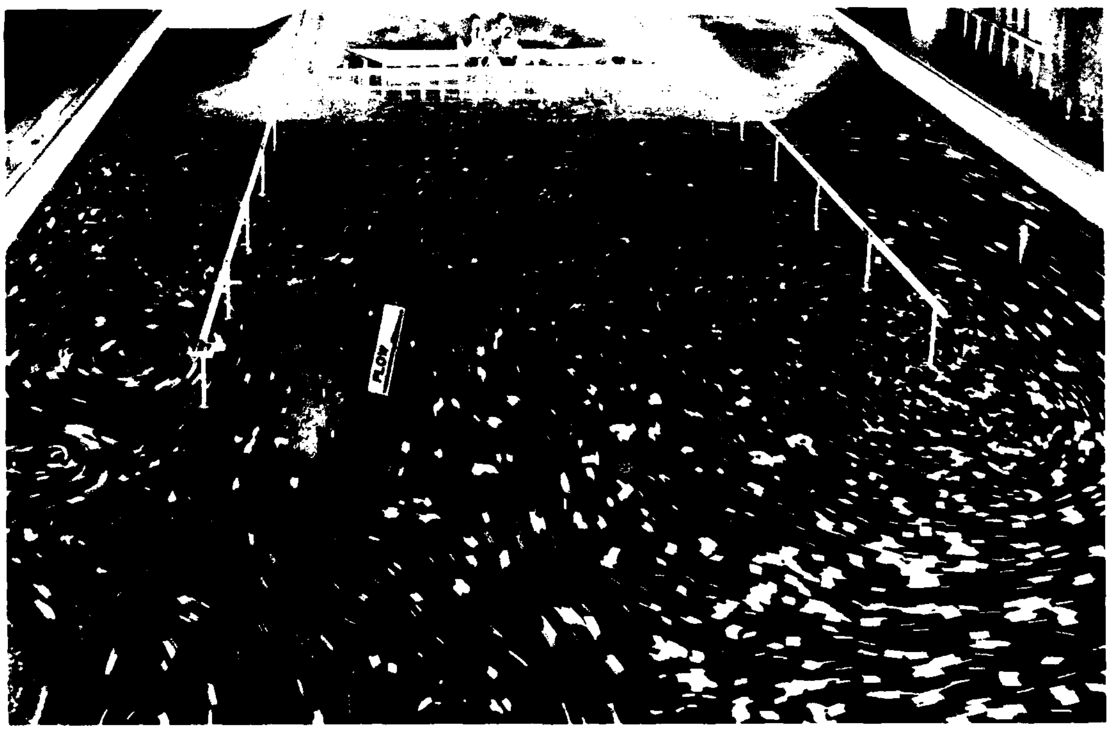


b. Pumps 1 and 2 operating

Photo 2. Cinque Hommes, surface flow patterns at pump intake, type 1 sump, discharge per pump 62.5 cfs, water-surface el 358.0, time exposure 16 sec (prototype)

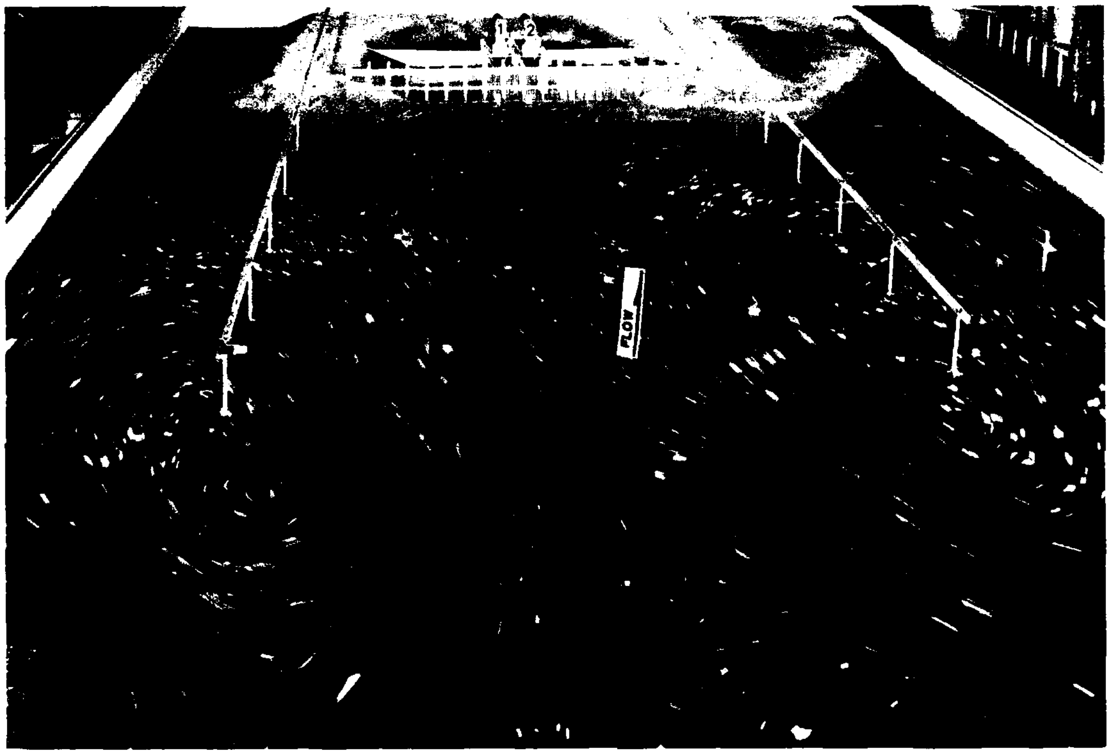


a. Pump 1 operating



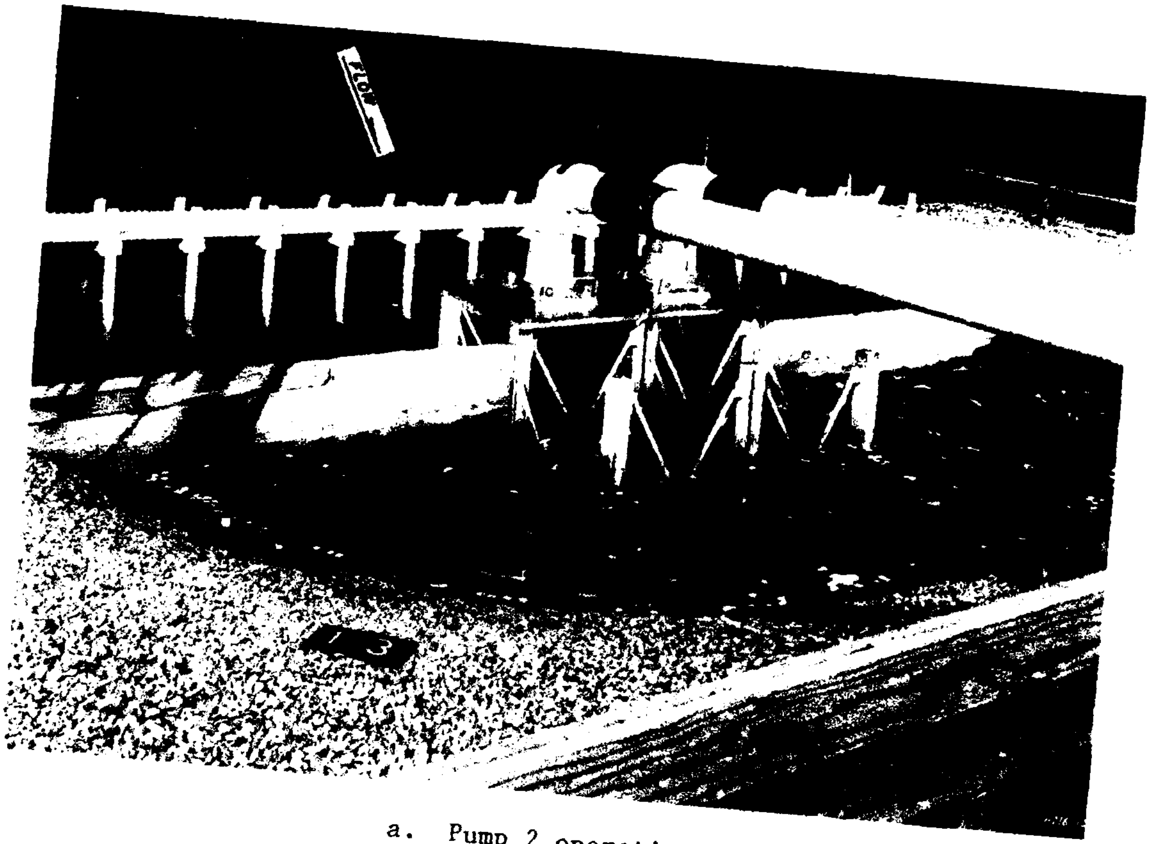
b. Pump 2 operating

Photo 3. Cinque Hommes, approach surface flow patterns, type 7 sump (recommended design), discharge per pump 62.5 cfs, water-surface el 358.0, time exposure 33 sec (prototype) (Continued)

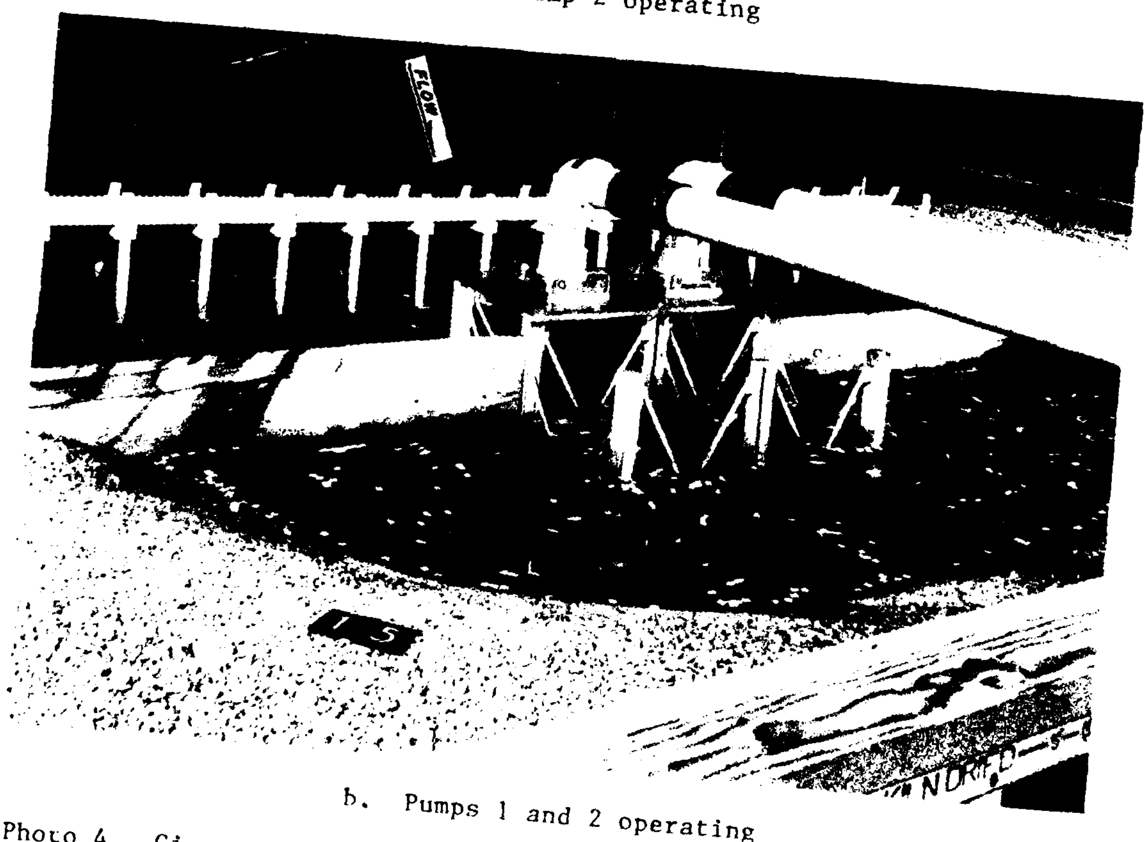


c. Pumps 1 and 2 operating

Photo 3. (Concluded)

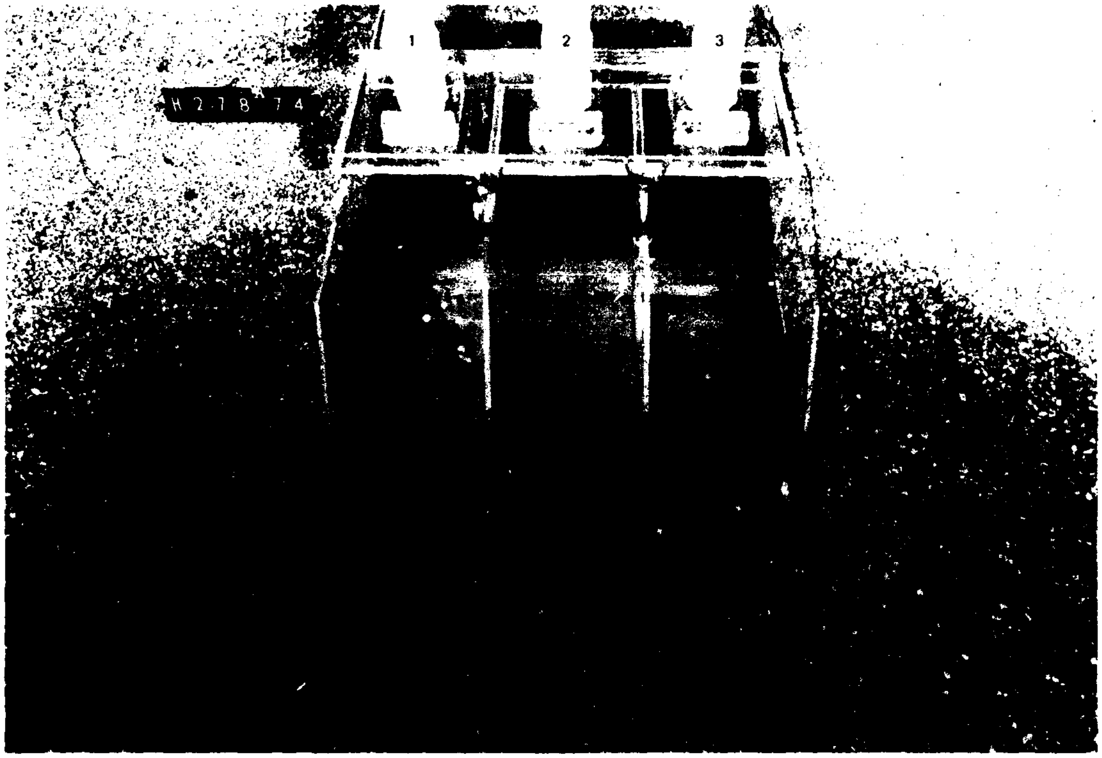


a. Pump 2 operating

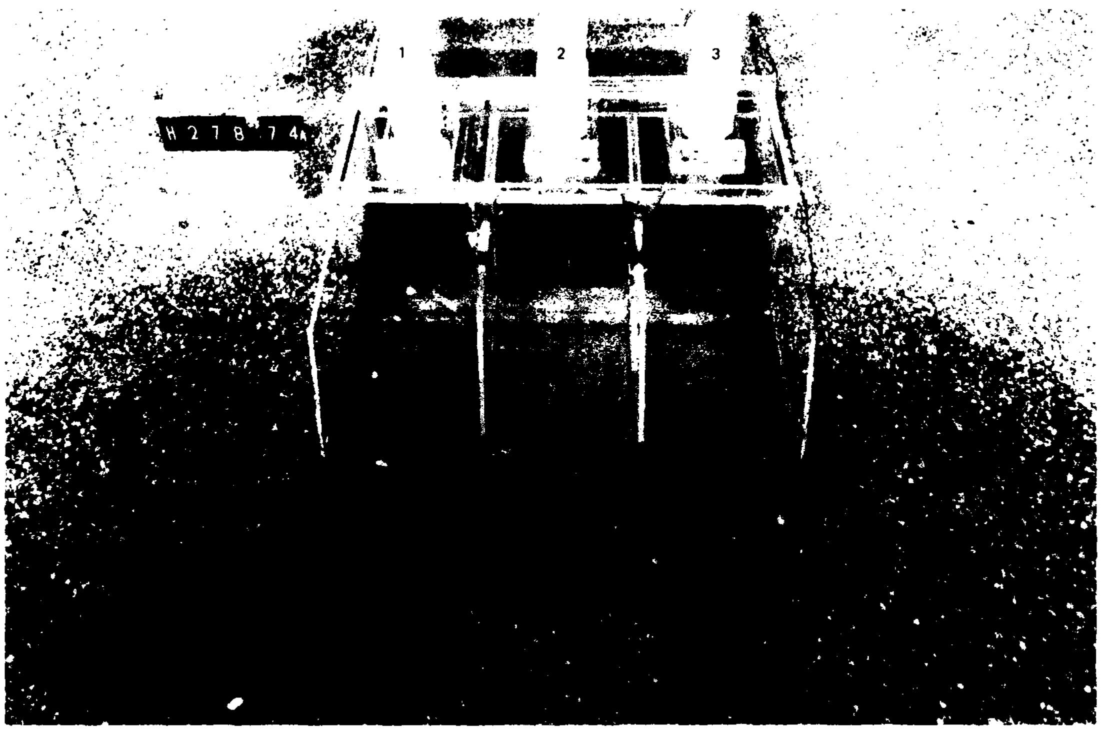


b. Pumps 1 and 2 operating

Photo 4. Cinque Hommes, surface flow patterns at pump intake, type 7 sump (recommended design), discharge per pump 62.5 cfs, water-surface el 358.0, time exposure 16 sec (prototype)

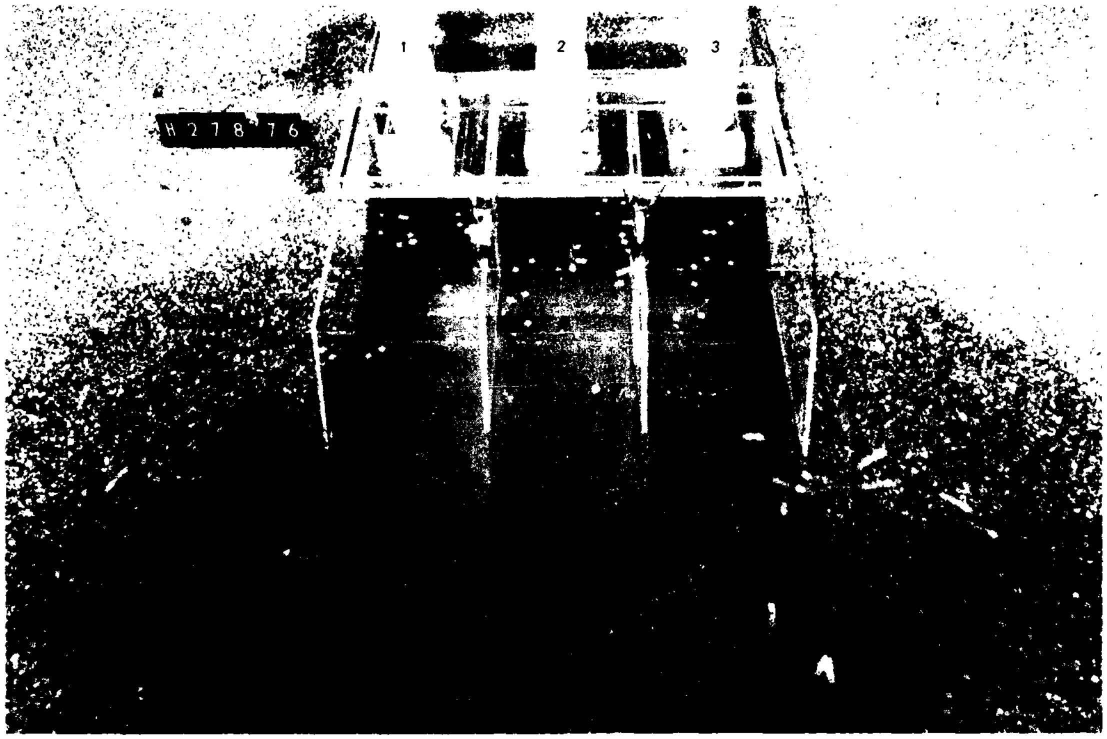


a. Dye injected on left side

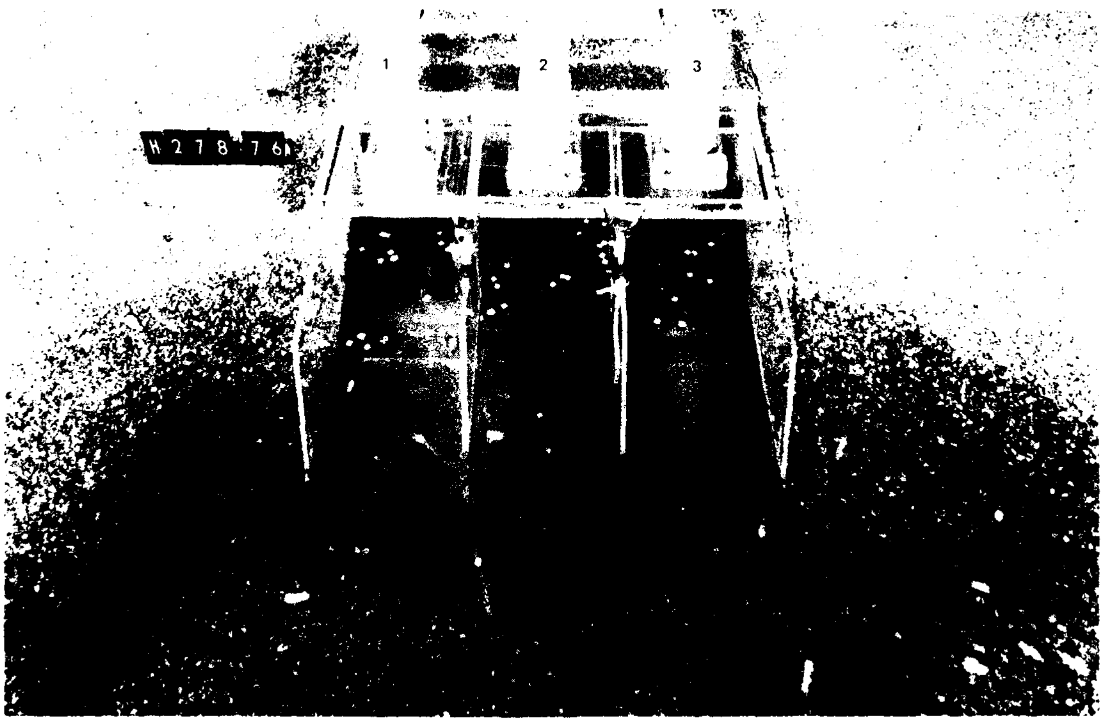


b. Dye injected on right side

Photo 5. Bois Brule, type 1 sump (without trashrack), bottom current patterns, pump 1 operating, discharge per pump 72 cfs, water-surface el 358.0

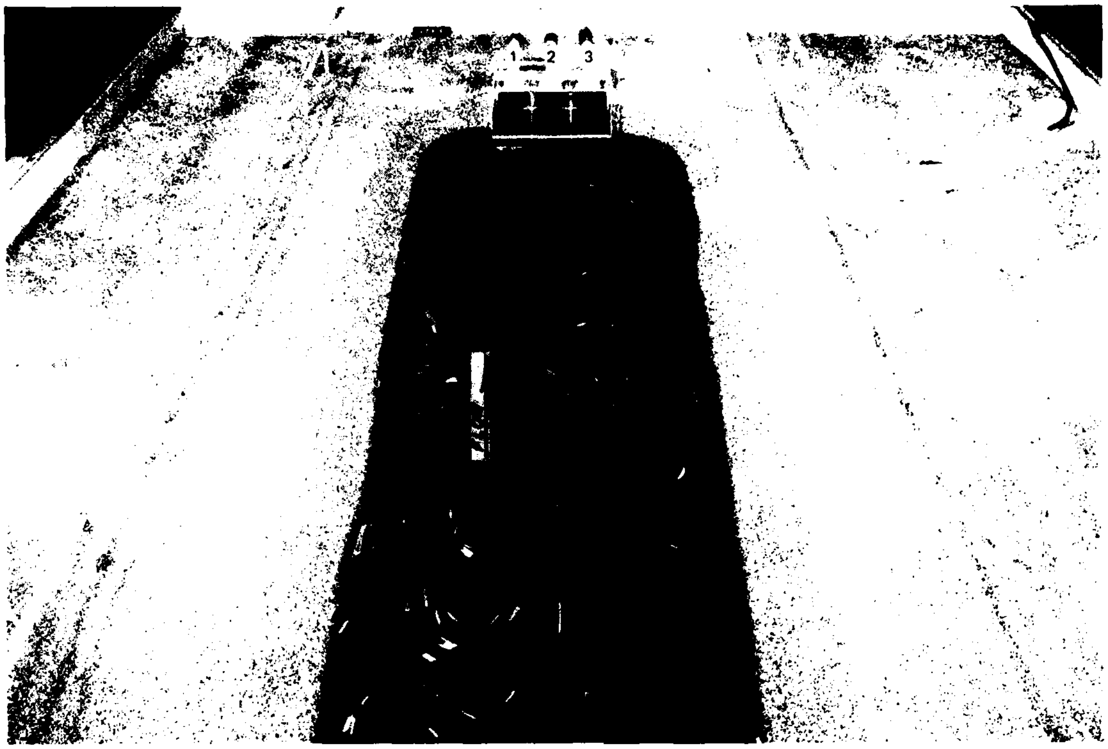


a. Dye injected on left side

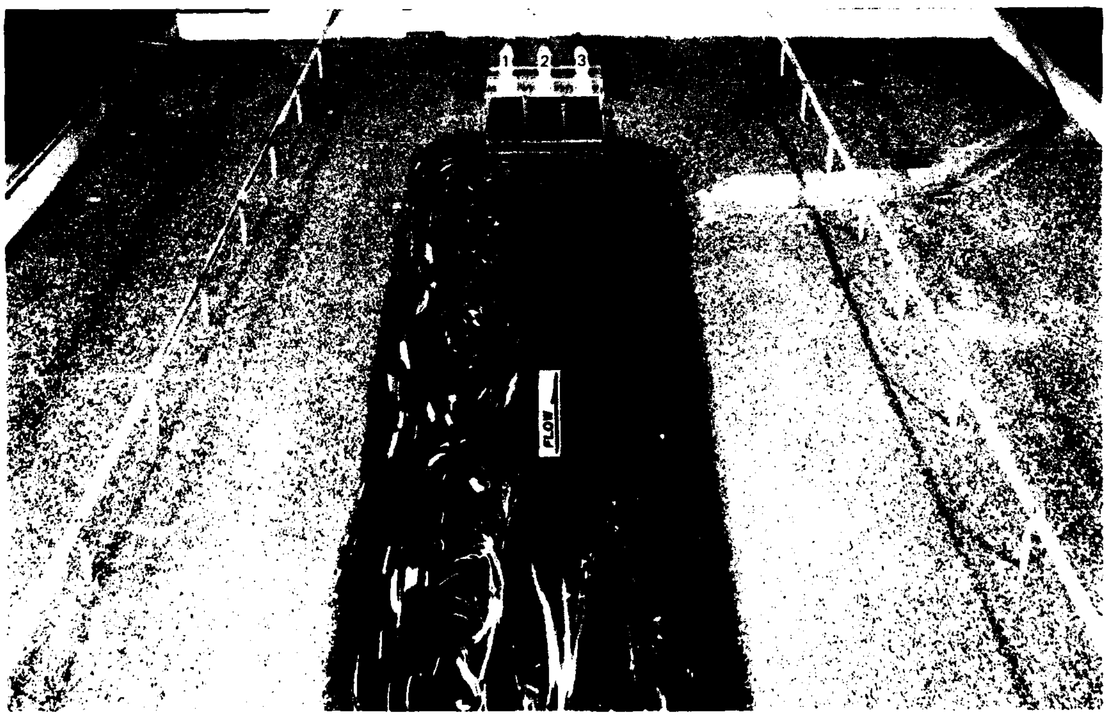


b. Dye injected on right side

Photo 6. Bois Brule, type 1 sump (without trashrack), bottom current patterns, pumps 1, 2, and 3 operating, discharge per pump 72 cfs, water-surface el 358.0

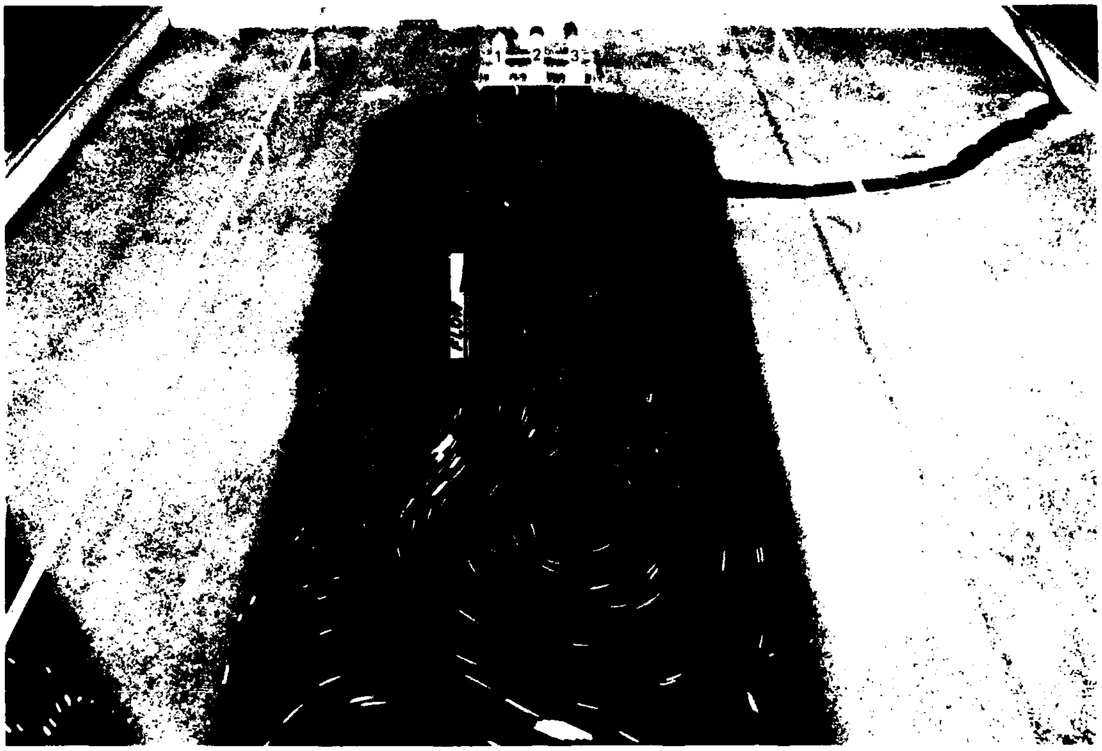


a. Pump 1 operating

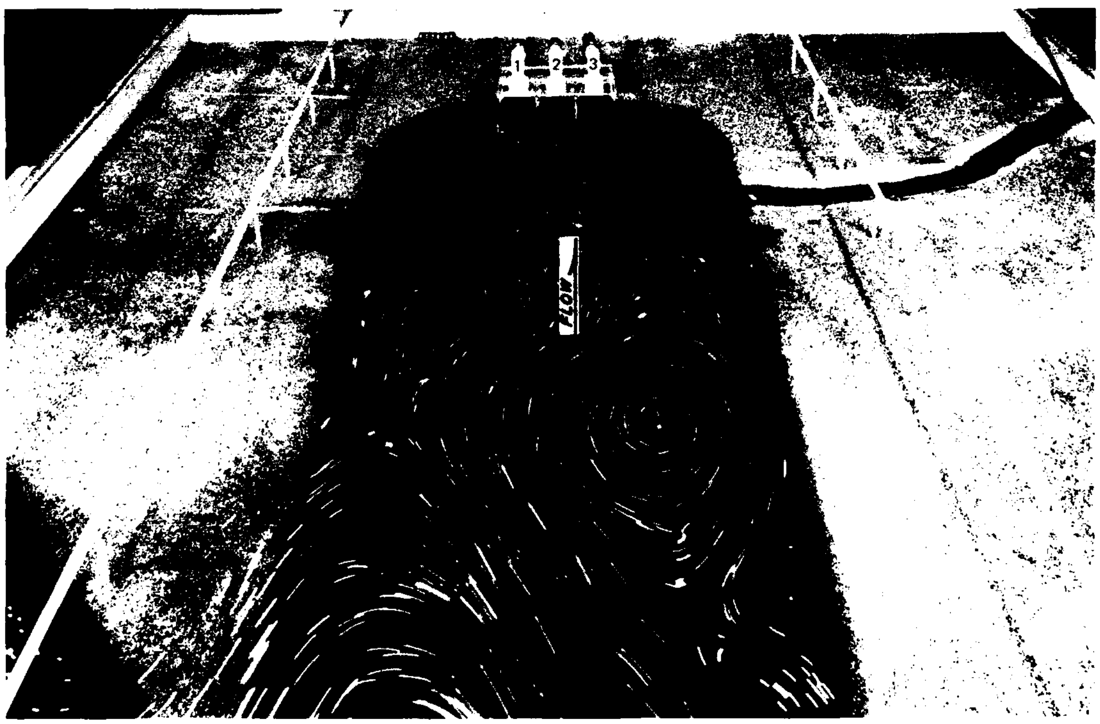


b. Pumps 1, 2, and 3 operating

Photo 7. Bois Brule, type 4 sump, type 2 trashrack, surface flow patterns, discharge per pump 72 cfs, water-surface el 358.0, time exposure 13 sec (prototype)

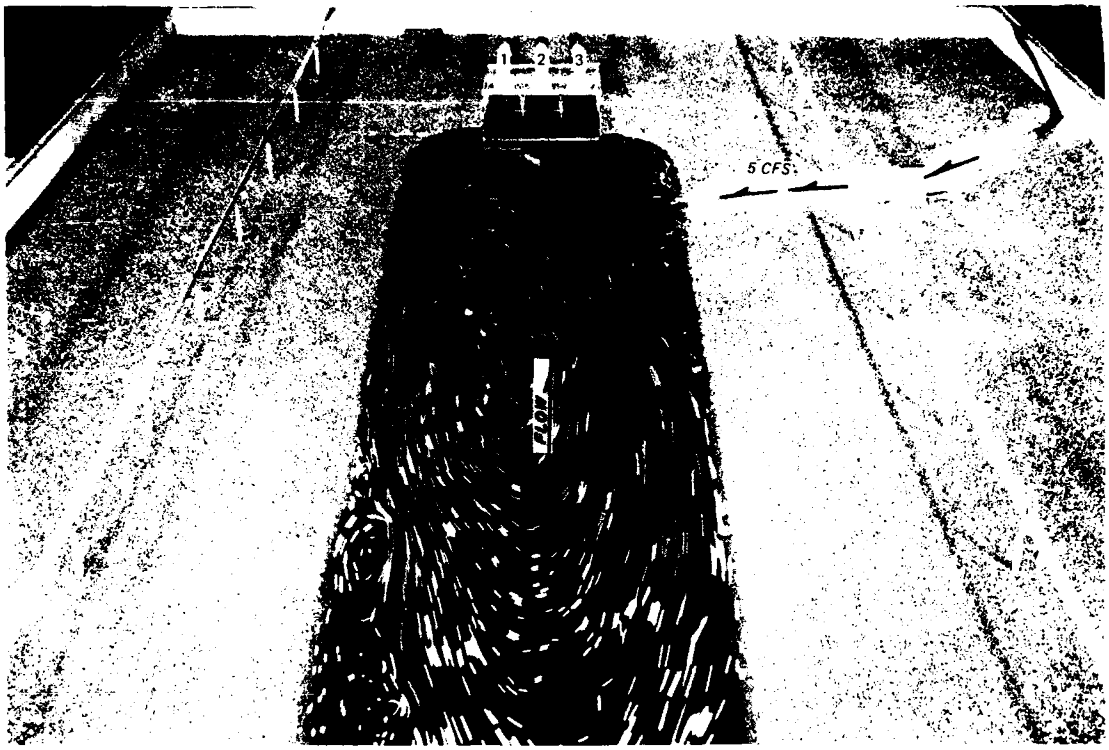


a. Pump 1 operating

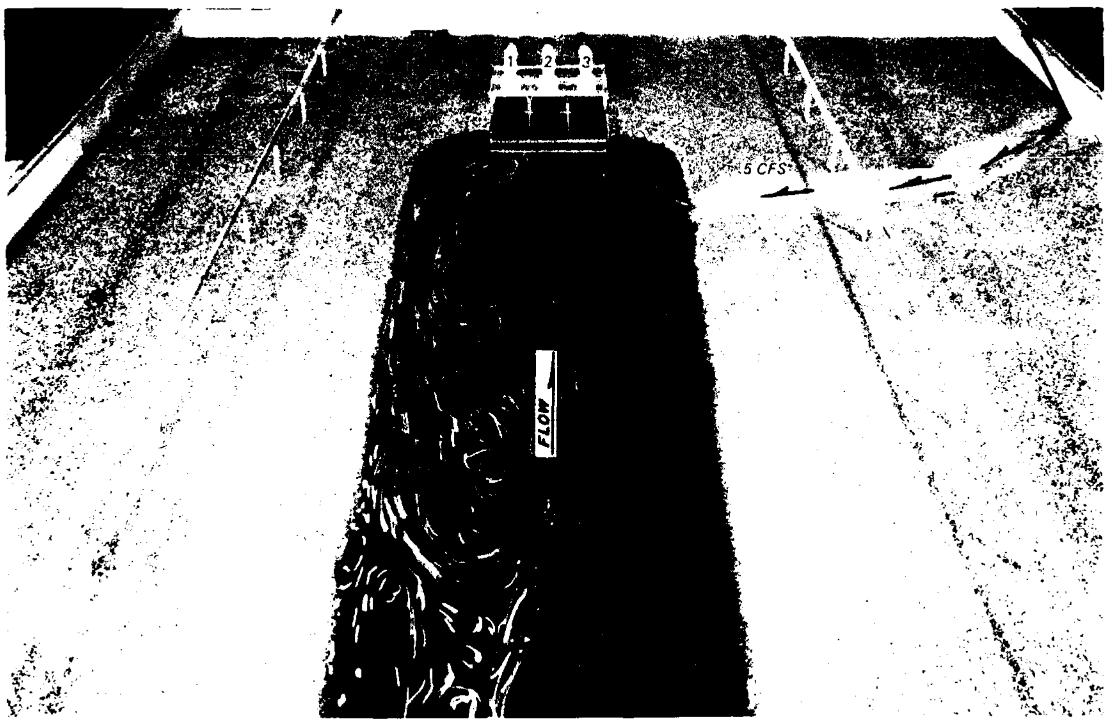


b. Pumps 1, 2, and 3 operating

Photo 8. Bois Brule, type 4 sump, type 2 trashrack, surface flow patterns, discharge per pump 72 cfs, water-surface el 362.0, time exposure 13 sec (prototype)



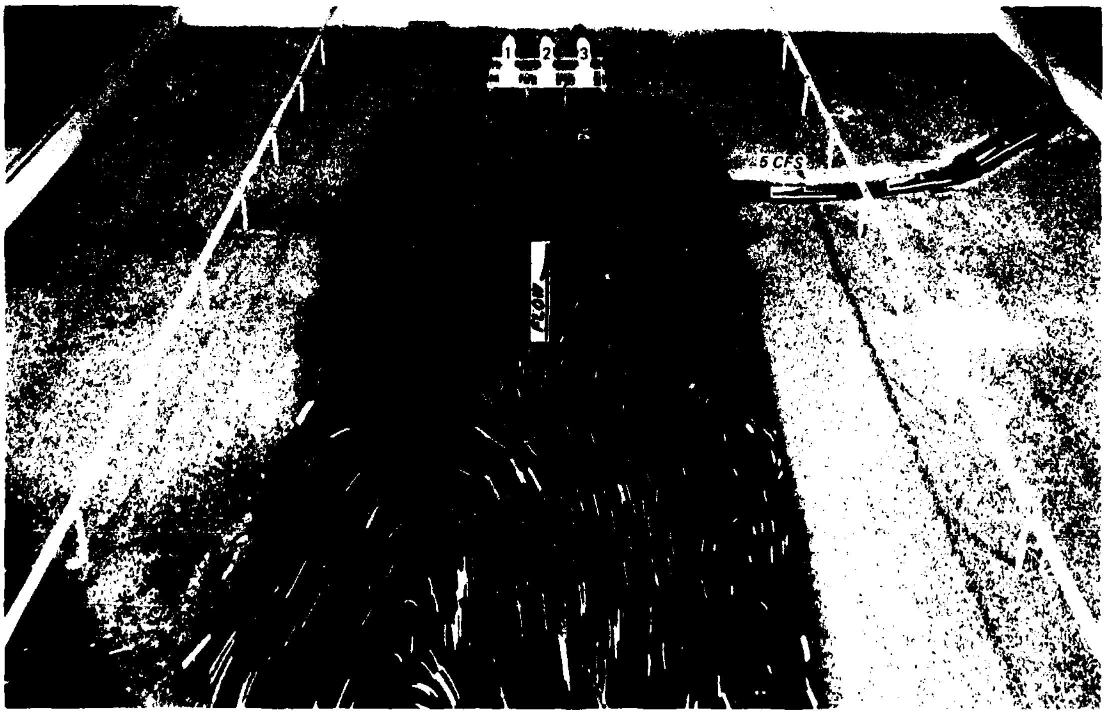
a. Pump 1 operating



b. Pumps 1, 2, and 3 operating

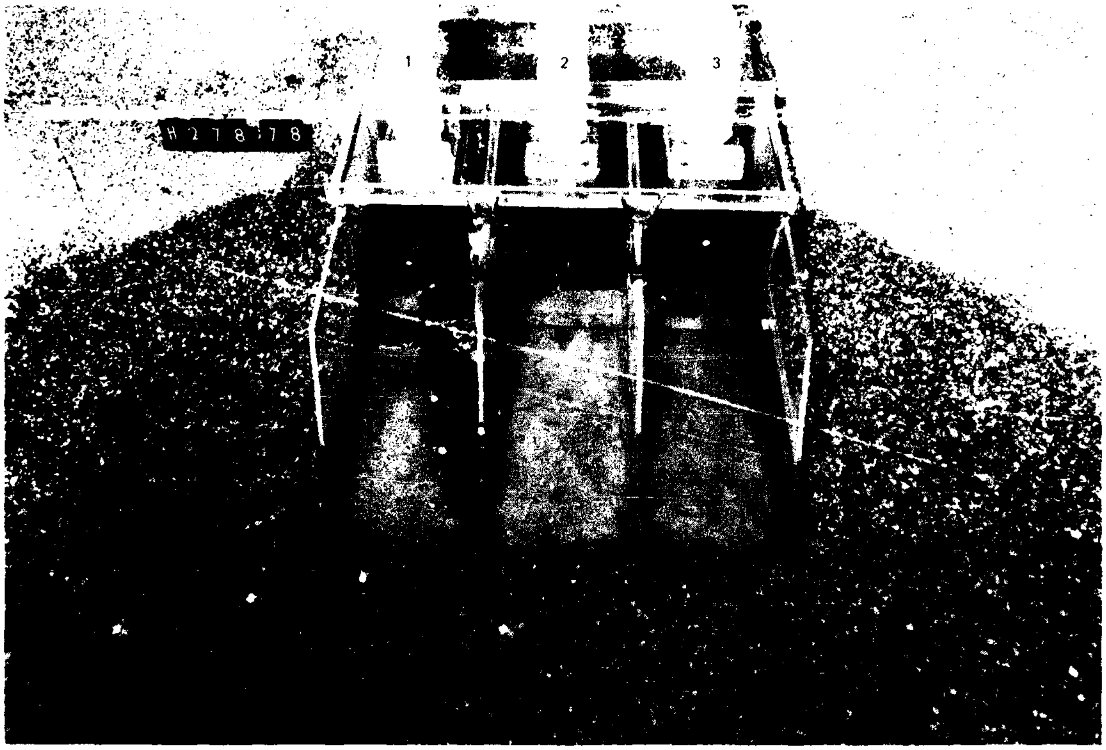
Photo 9. Bois Brule, type 4 sump, type 2 trashrack, 5-cfs flow in side channel, discharge per pump 72 cfs, water-surface el 358.0, time exposure 13 sec (prototype)

a. Pump 1 operating



b. Pumps 1, 2, and 3 operating

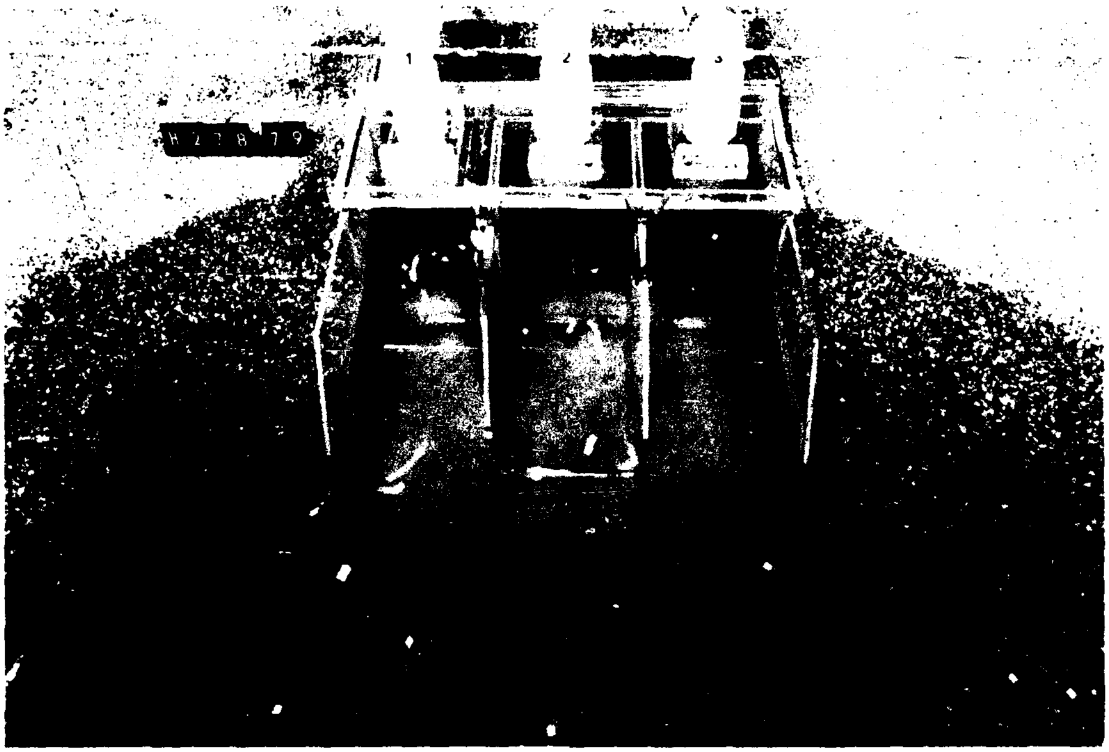
Photo 10. Bois Brule, type 4 sump, type 2 trashrack, 5-cfs flow in side channel, discharge per pump 72 cfs, water-surface el 362.0, time exposure 13 sec (prototype)



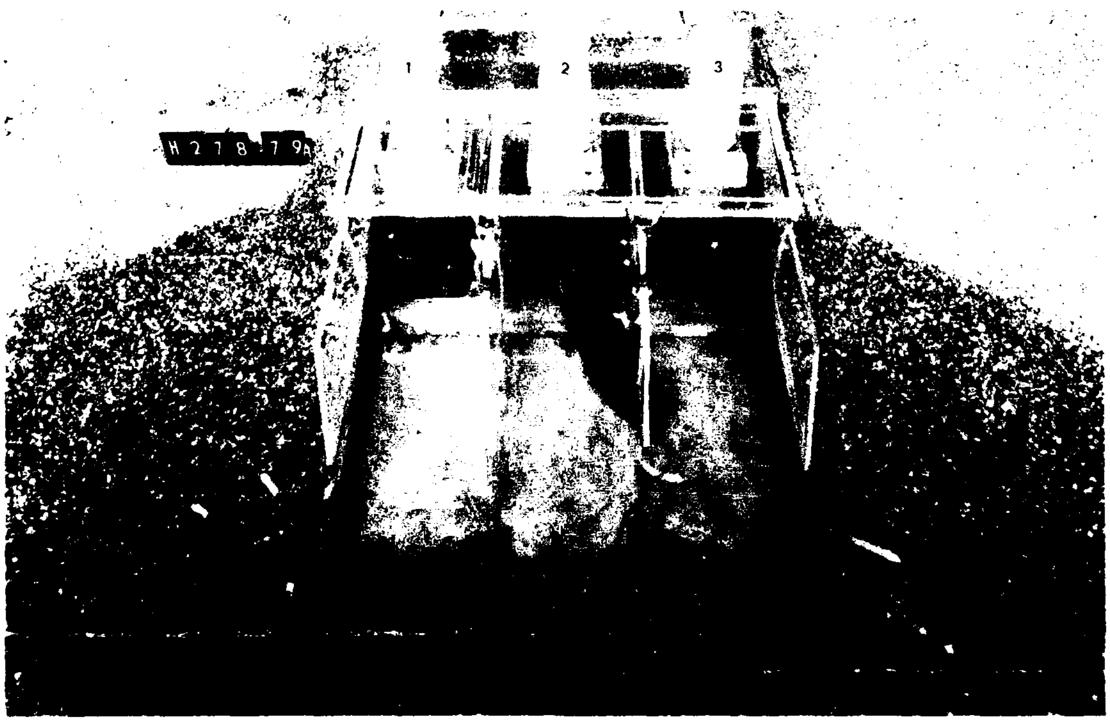
a. Pump 1 operating, dye injected upstream of passageway 1

b. Pump 1 operating, dye injected in passageway 1

Photo 11. Bois Brule, type 4 sump (without trashrack), bottom flow patterns, discharge per pump 72 cfs, water-surface el 358.0 (Continued)

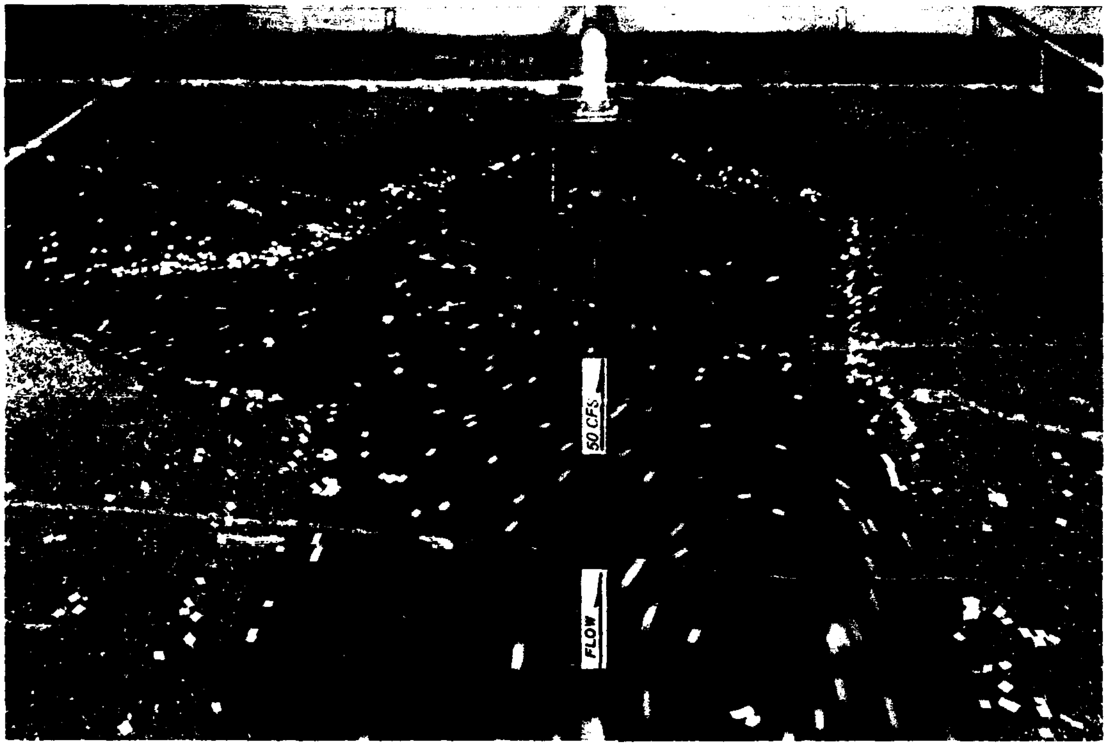


c. Pumps 1 and 2 operating, dye injected in passageway 1

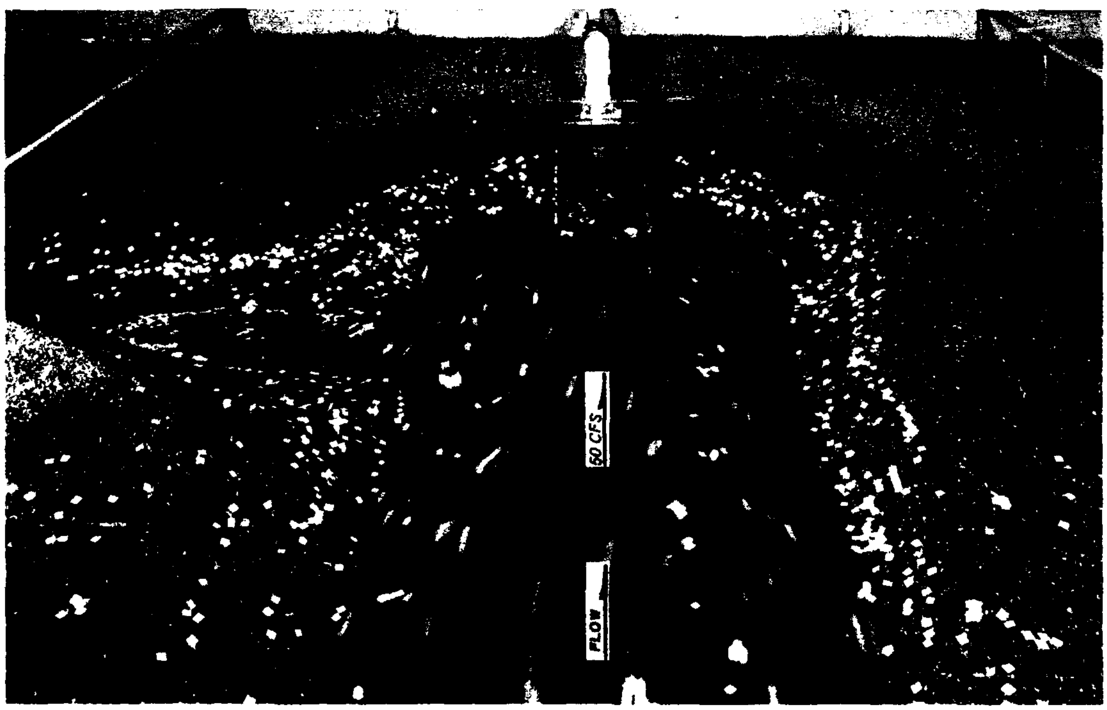


d. Pumps 1 and 2 operating, dye injected in passageway 2

Photo 11. (Concluded)

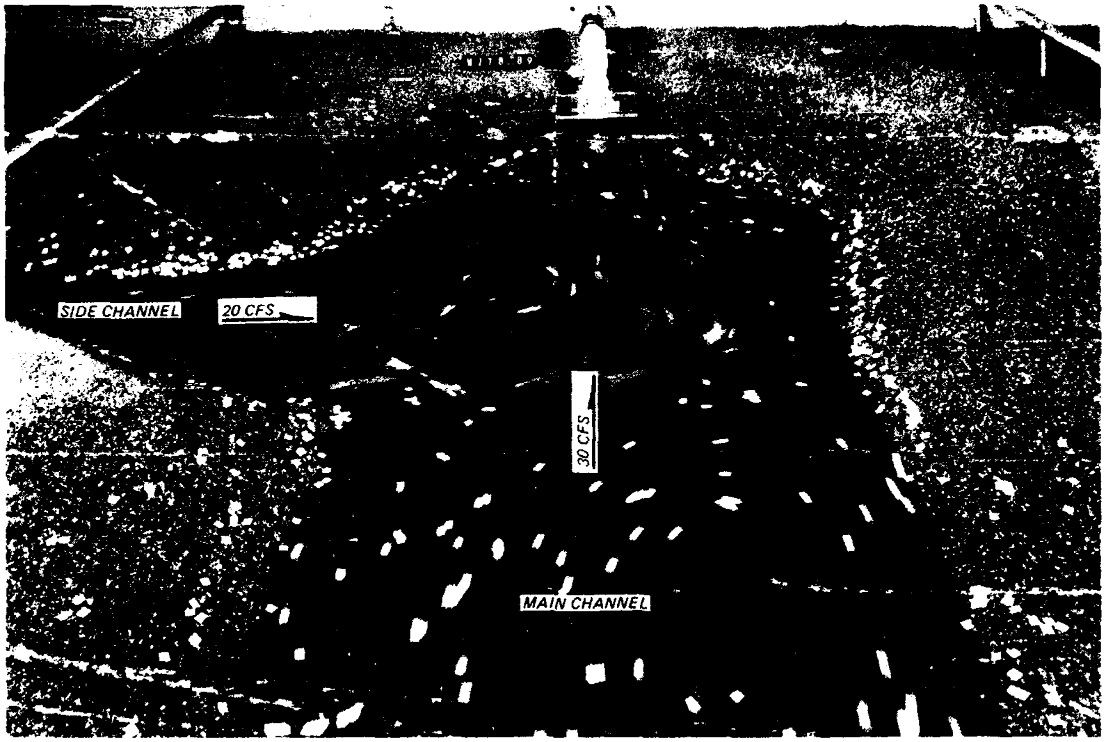


a. Water-surface el 356.0

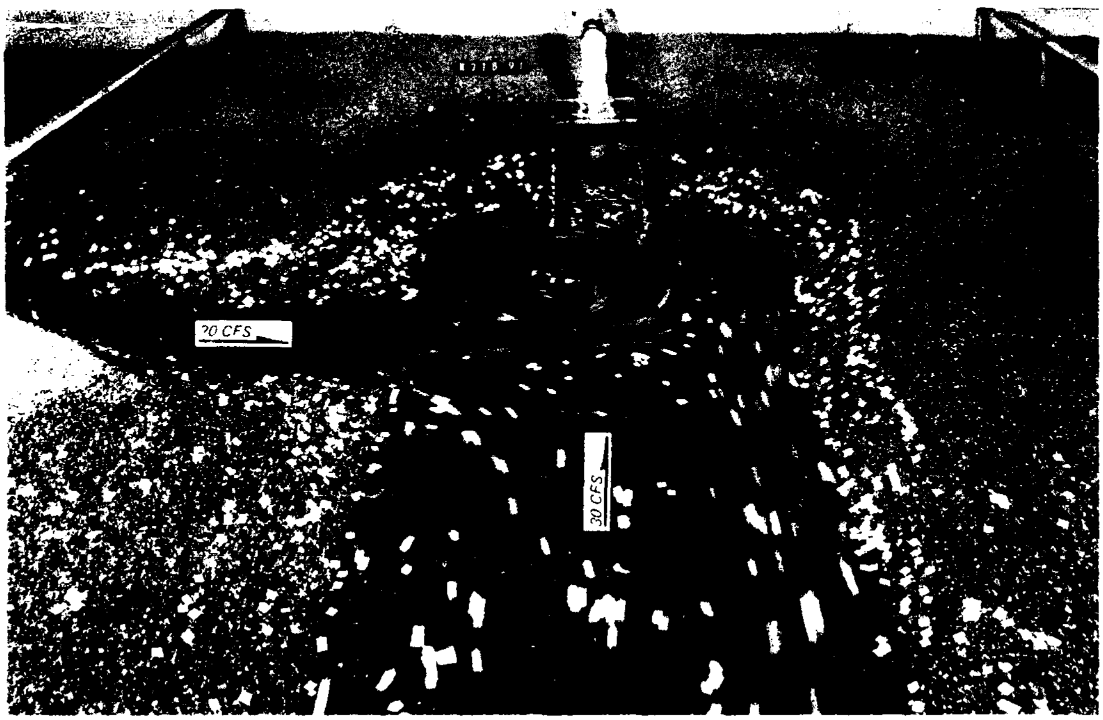


b. Water-surface el 354.0

Photo 12. Missouri Chute, type 1 sump, surface flow patterns, pump discharge 50 cfs

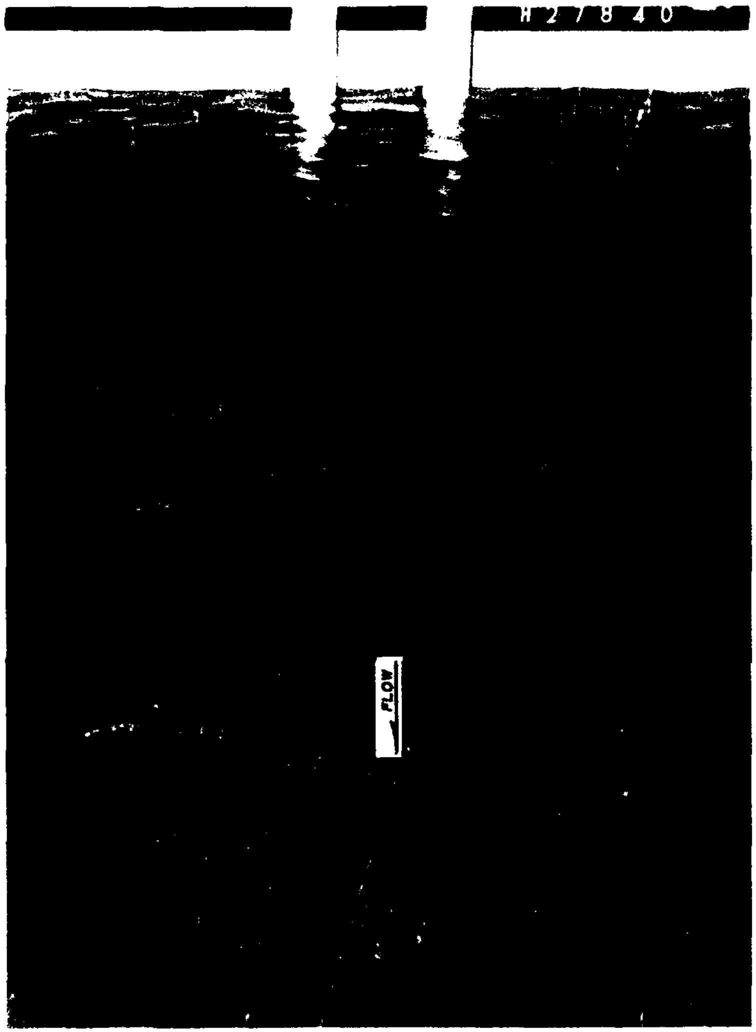


a. Water-surface el 356.0

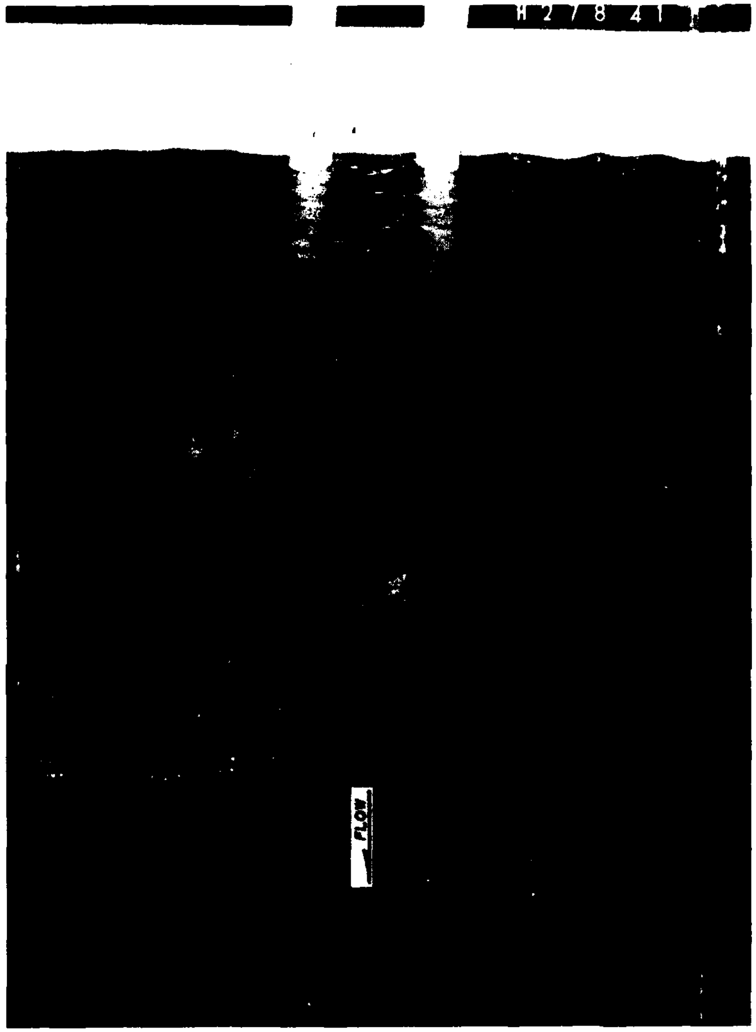


b. Water-surface el 354.0

Photo 13. Missouri Chute, type 1 design, surface flow patterns, side channel discharge 20 cfs, main channel discharge 30 cfs, time exposure 6 sec (prototype)



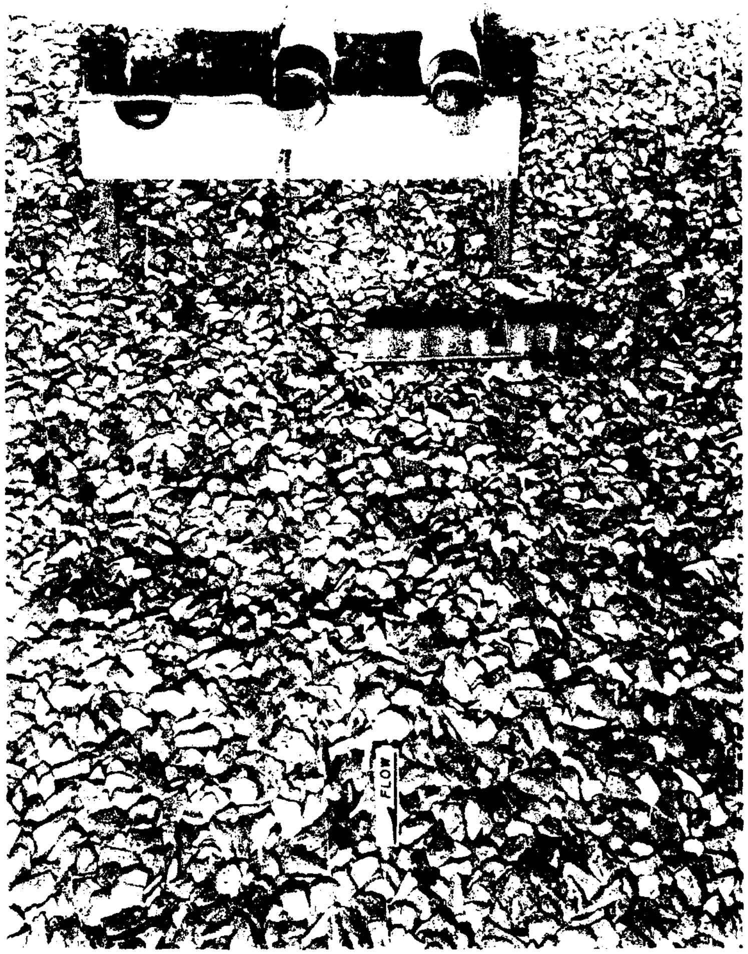
a. Tailwater el 366.0



b. Tailwater el 361.0

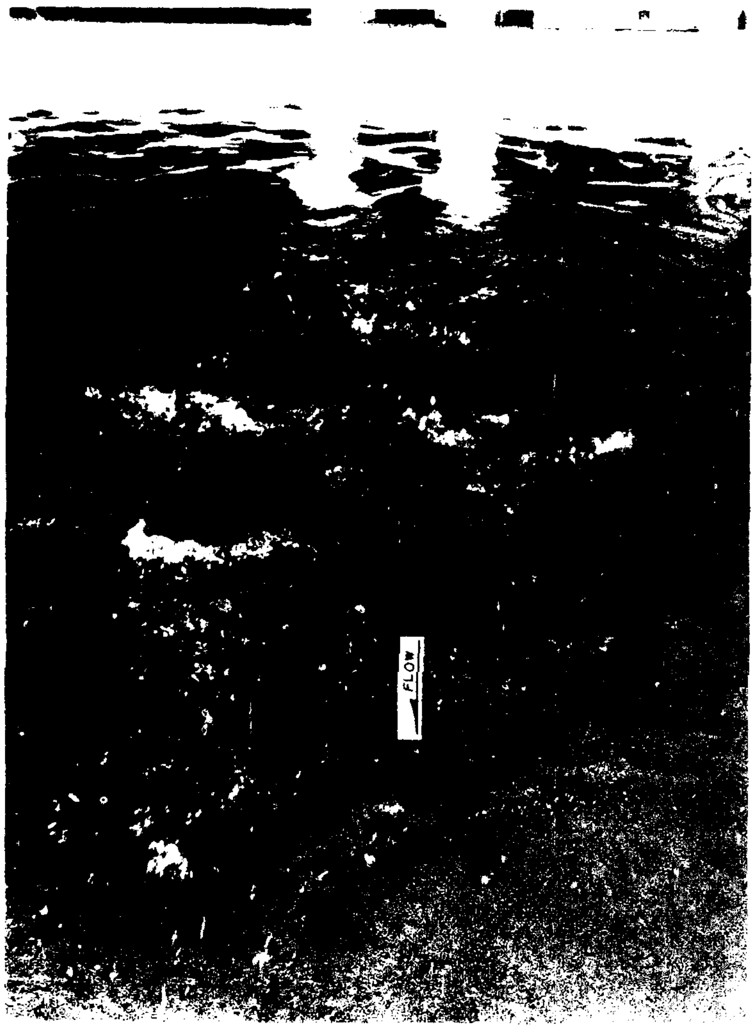
Photo 14. Cinque Hommes, type 1 outlet, 45-deg saxophone outlets, one pump operating, discharge 62.5 cfs, riprap size d_{50} = 8.75 in. (Continued)

c. Tailwater el 344.0

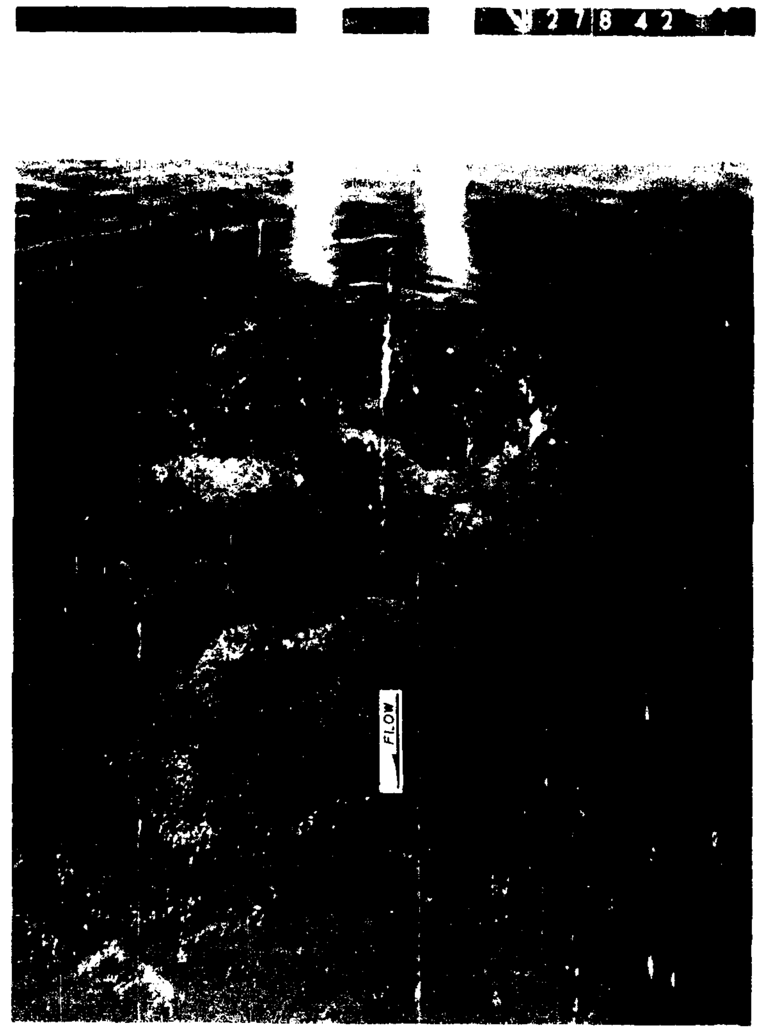


d. Dry bed. Rock failure resulting from tailwater el 344.0 for a period of 2.5 hr (prototype)

Photo 14. (Concluded)



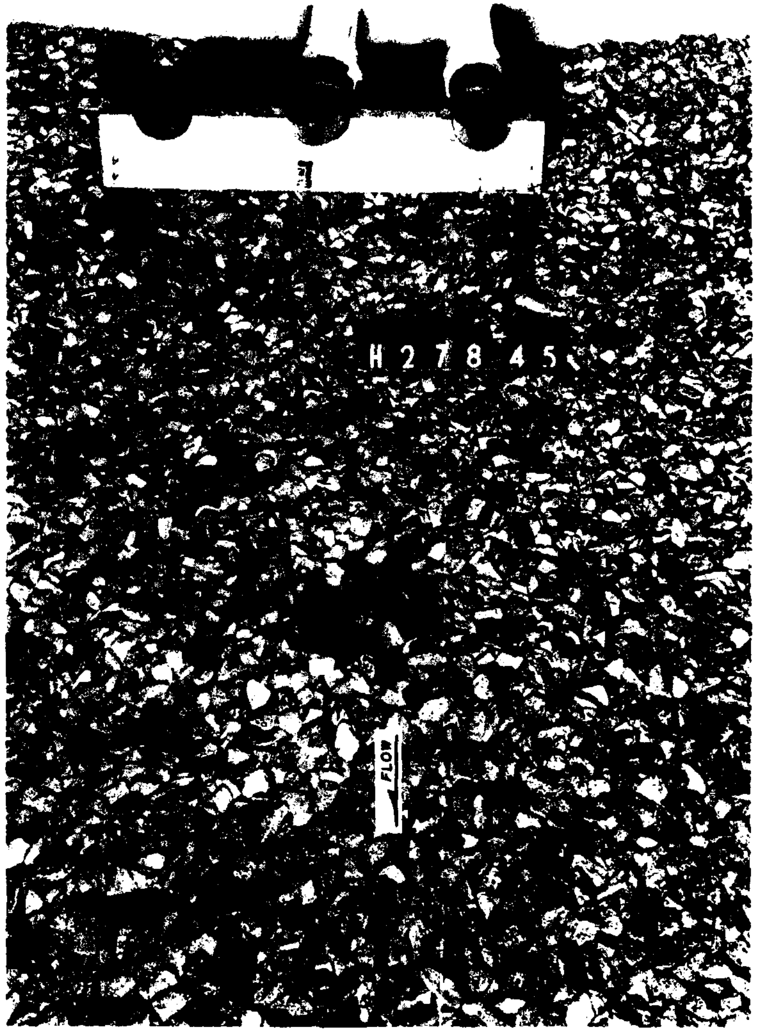
a. Tailwater el 366.0



b. Tailwater el 361.0

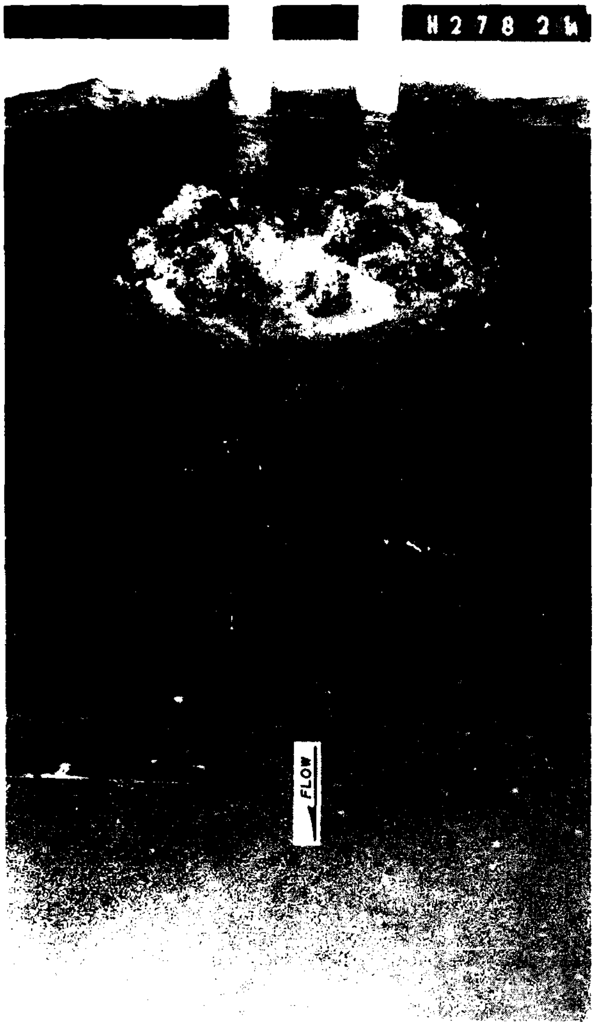
Photo 15. Cinque Hommes, type 1 outlet, 45-deg saxophone outlets, both pumps operating, riprap size d_{50} = 8.75 in. (Continued)

c. Tailwater el 347.0 rock displacement observed

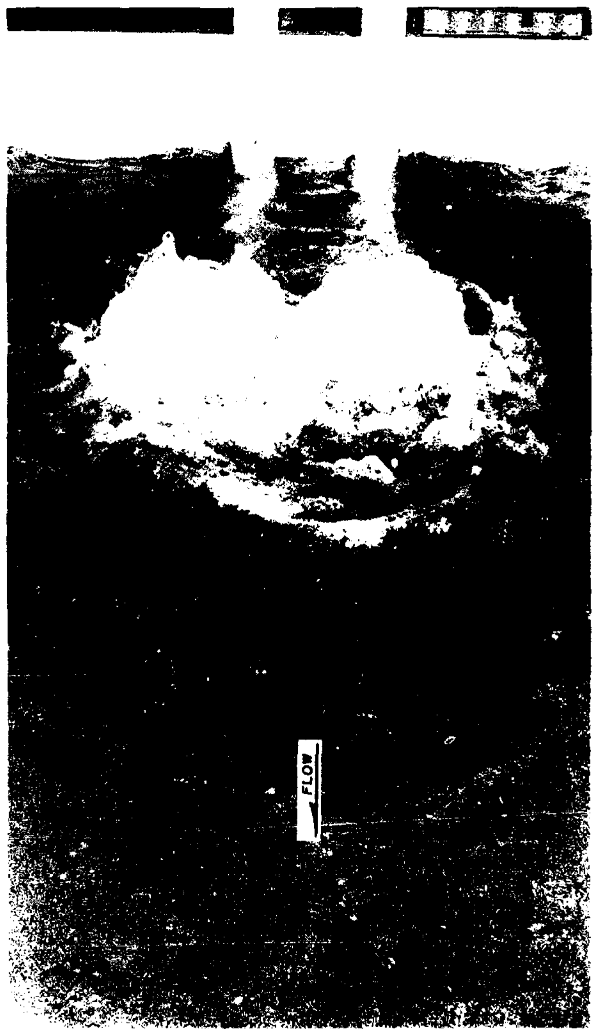


d. Dry bed. Rock failure resulting from tailwater el 347.0 for a period of 2.5 hr (prototype)

Photo 15. (Concluded)



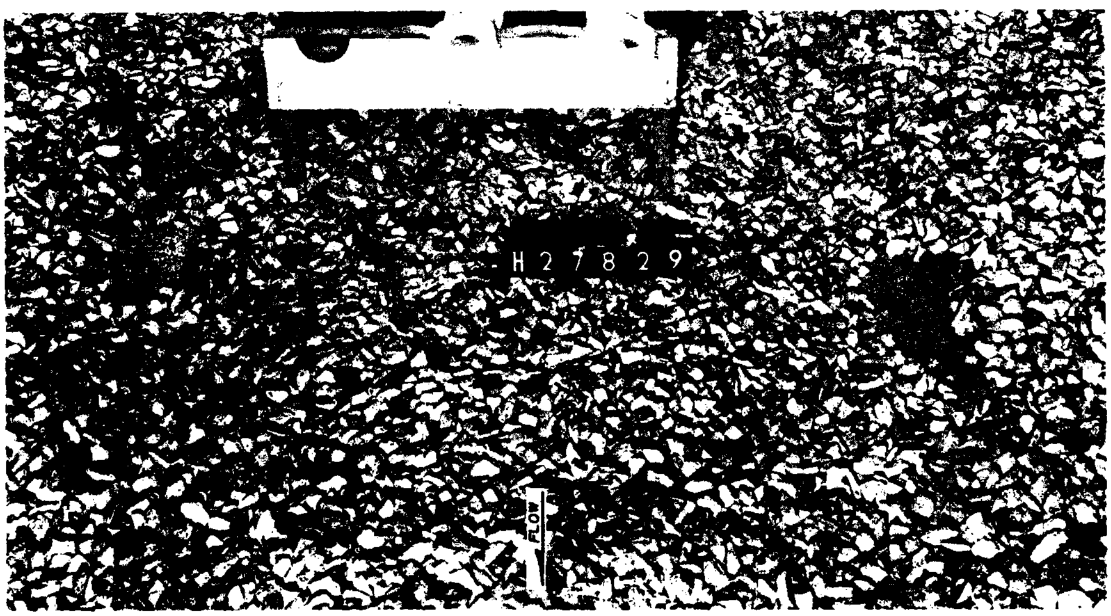
a. Tailwater el 366.0



b. Tailwater el 361.0

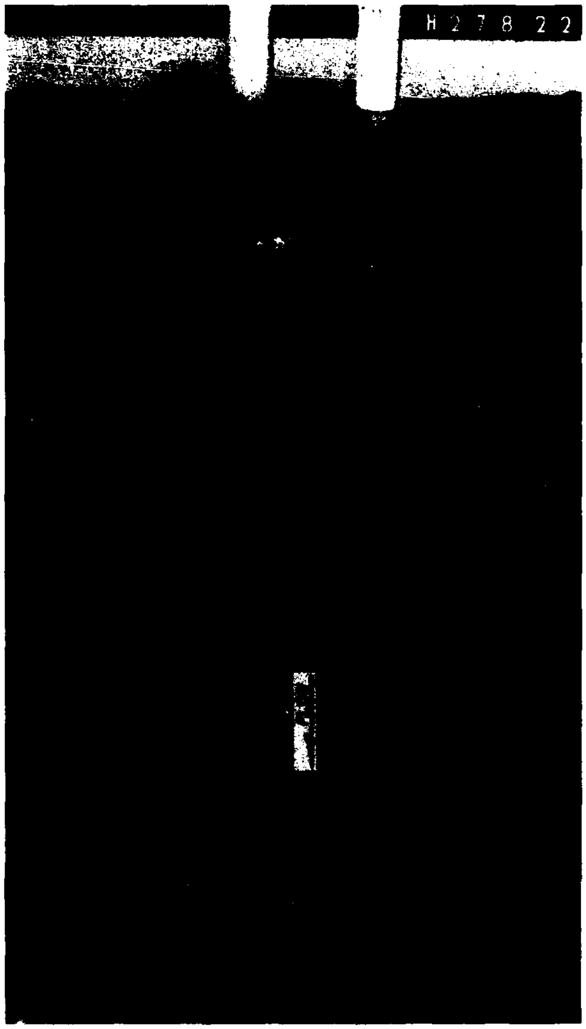
Photo 16. Cinque Hommes, type 2 outlet, 90-deg outlet, both pumps operating, discharge per pump 62.5 cfs, riprap size d_{50} = 8.75 in. (Continued)

c. Tailwater el 345.0

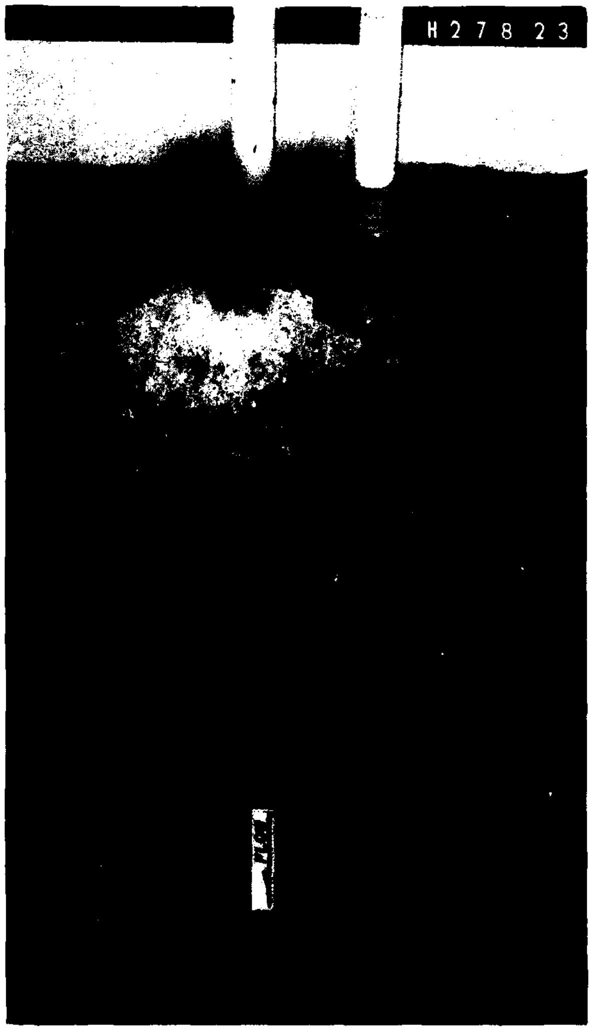


d. Dry bed. Rock failure resulting from tailwater el 345.0 for a period of 2.5 hr (prototype)

Photo 16. (Concluded)



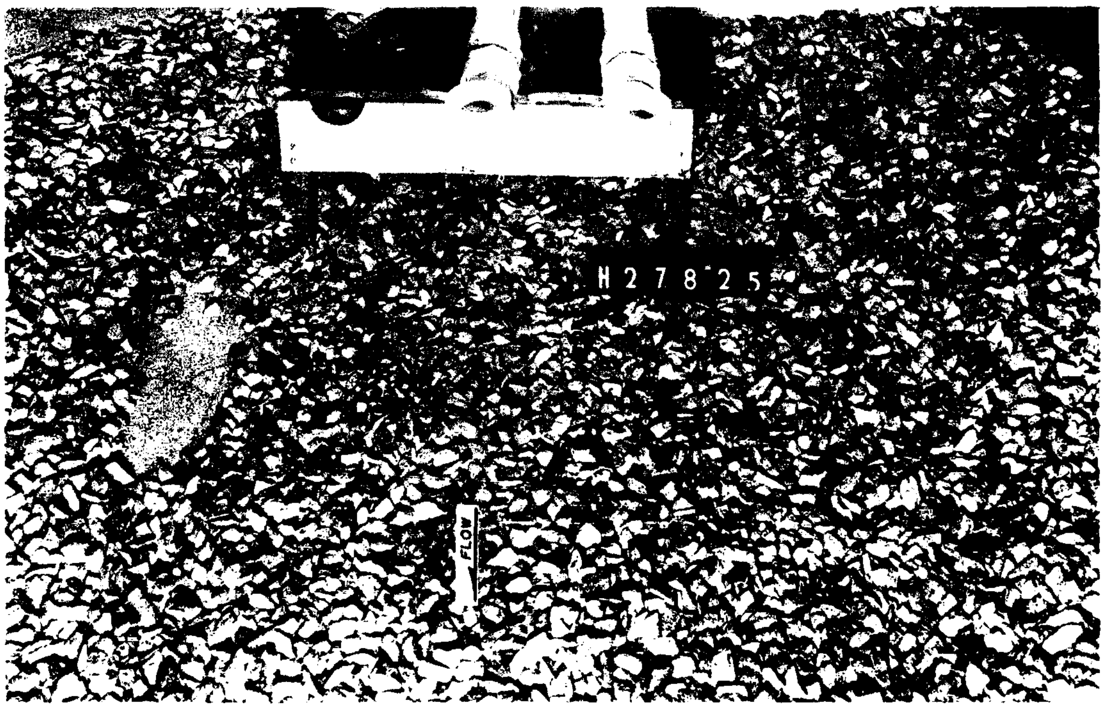
a. Tailwater el 366.0



b. Tailwater el 361.0

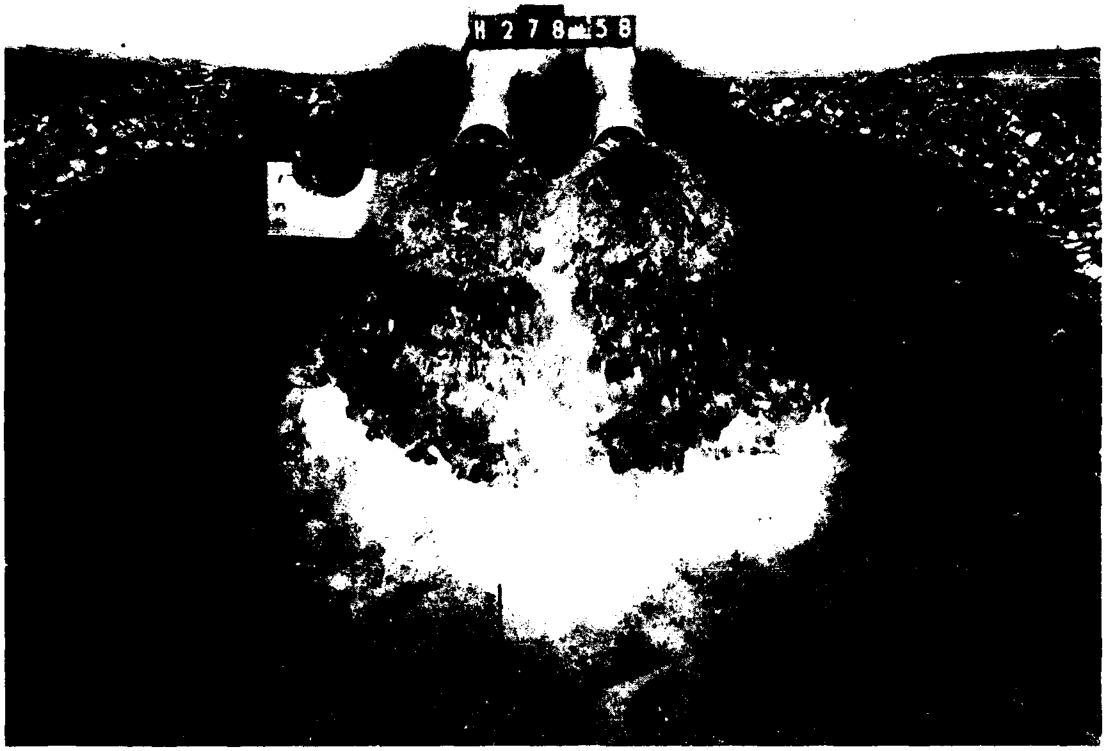
Photo 17. Cinque Hommes, type 2 outlet, 90-deg outlet, one pump operating, discharge 62.5 cfs, riprap size d_{50} = 8.75 in. (Continued)

c. Tailwater el 344.0

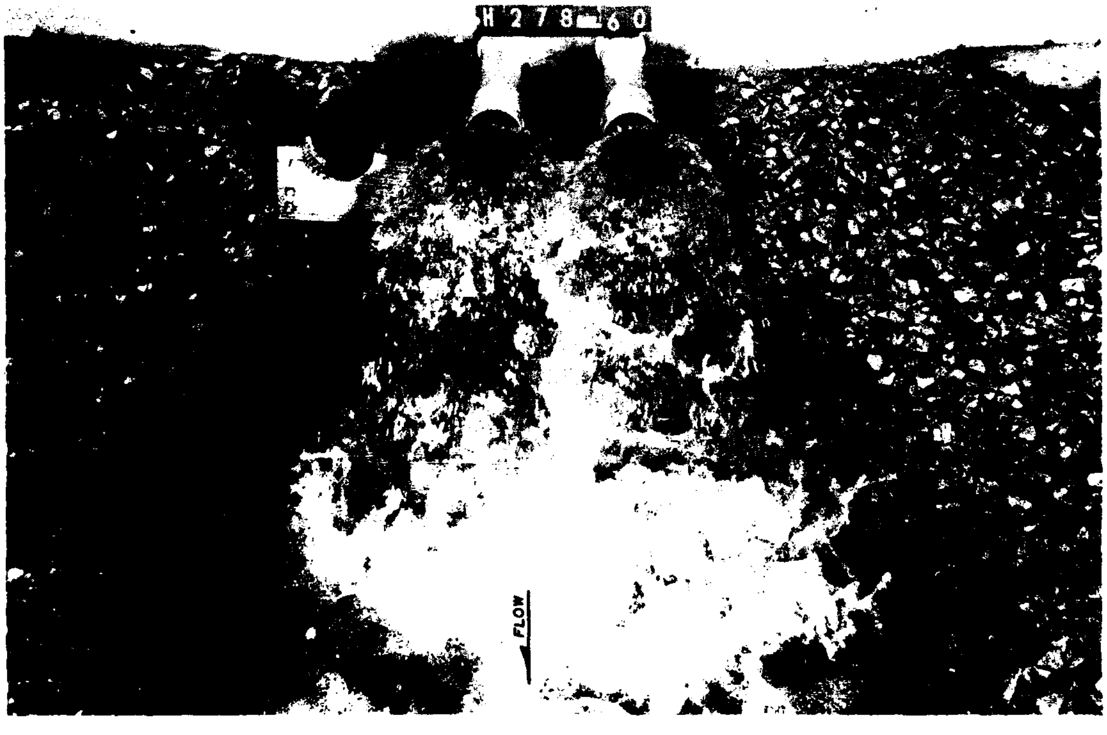


d. Dry bed. Rock failure resulting from tailwater el 344.0 for a period of 2.5 hr (prototype)

Photo 17. (Concluded)

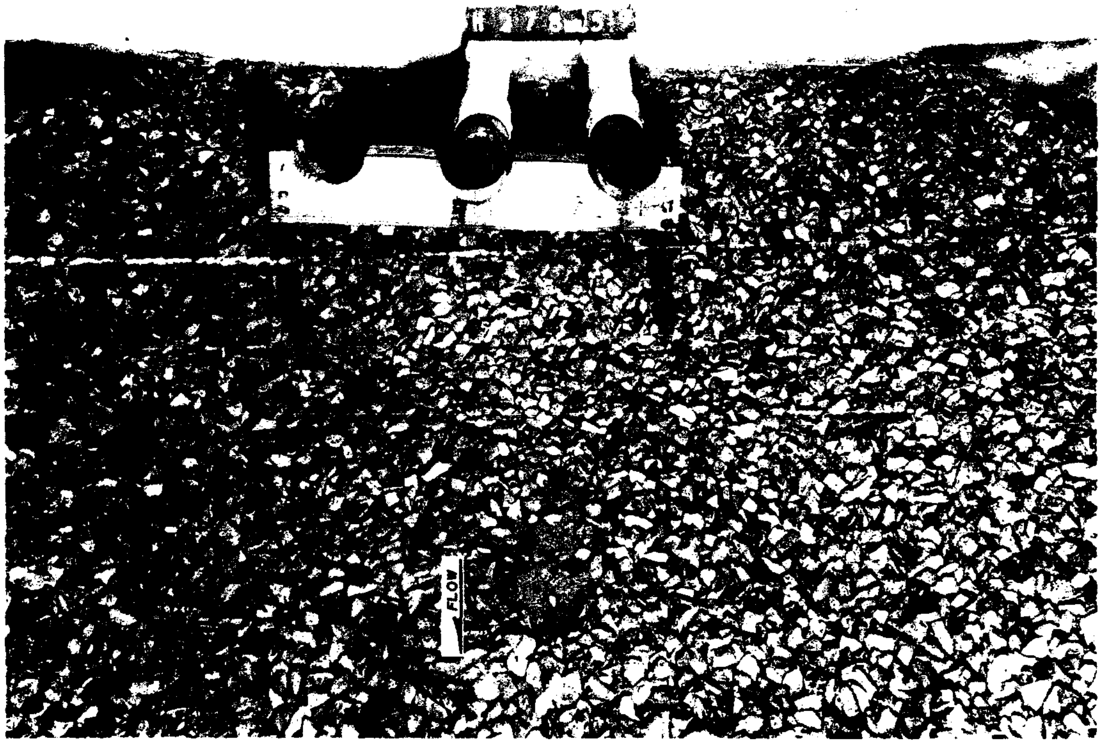


a. Tailwater el 360.0



b. Tailwater el 345.0

Photo 18. Jones Cutoff, type 2 outlet, 45-deg outlet, both pumps operating, discharge 62.5 cfs per pump, riprap size d_{50} = 8.75 in. (Continued)



c. Dry bed. Rock failure resulting from tailwater el 345.0 for a period of 2.5 hr (prototype)

Photo 18. (Concluded)

a. Tailwater el 361.0

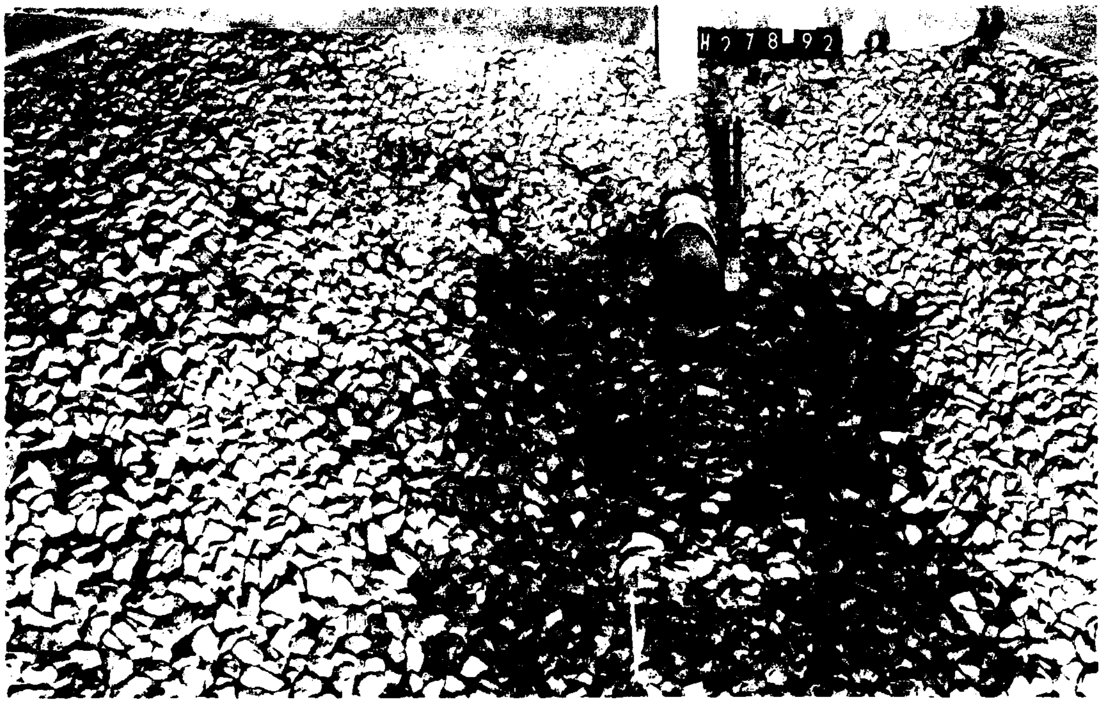
b. Tailwater el 358.0

Photo 19. Bois Brule 45-deg outlet, all pumps operating, discharge 72.0 cfs per pump, riprap size d_{50} = 8.75 in. (Continued)

c. Dry bed. Rock failure resulting from tailwater el 358.0 for a period of 2.5 hr (prototype)

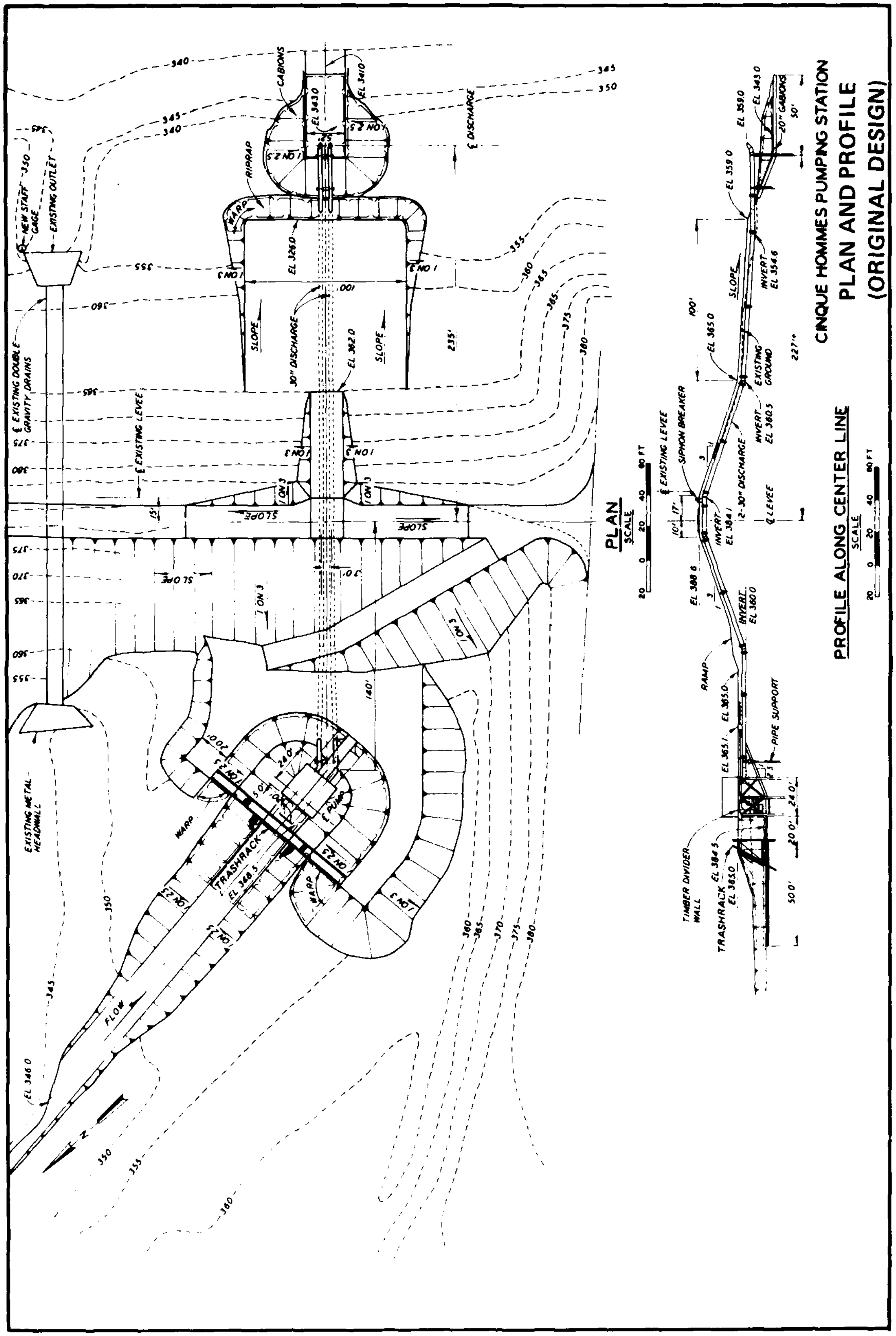
Photo 19. (Concluded)

a. Tailwater el 355.0



b. Dry bed. Rock failure resulting from tailwater el 355.0 for a period of 2.5 hr (prototype)

Photo 20. Missouri Chute, 45-deg outlet, discharge 50 cfs, riprap size d_{50} = 8.75 in.


CINQUE HOMMES PUMPING STATION
PLAN AND PROFILE
(ORIGINAL DESIGN)
PLAN
SCALE
PROFILE ALONG CENTER LINE
SCALE
CABIONS
RIPRAP
WARP
SLOPE
30" DISCHARGE
℄ DISCHARGE
℄ EXISTING LEVEE
℄ EXISTING DOUBLE GRAVITY DRAINS
NEW STAFF GAGE
EXISTING OUTLET
EXISTING METAL HEADWALL
TRASHRACK
PUMP
FLOW
SIPHON BREAKER
2-30" DISCHARGE
℄ LEVEE
EXISTING GROUND
RAMP
PIPE SUPPORT
TIMBER DIVIDER WALL
INVERT
20" GABIONS

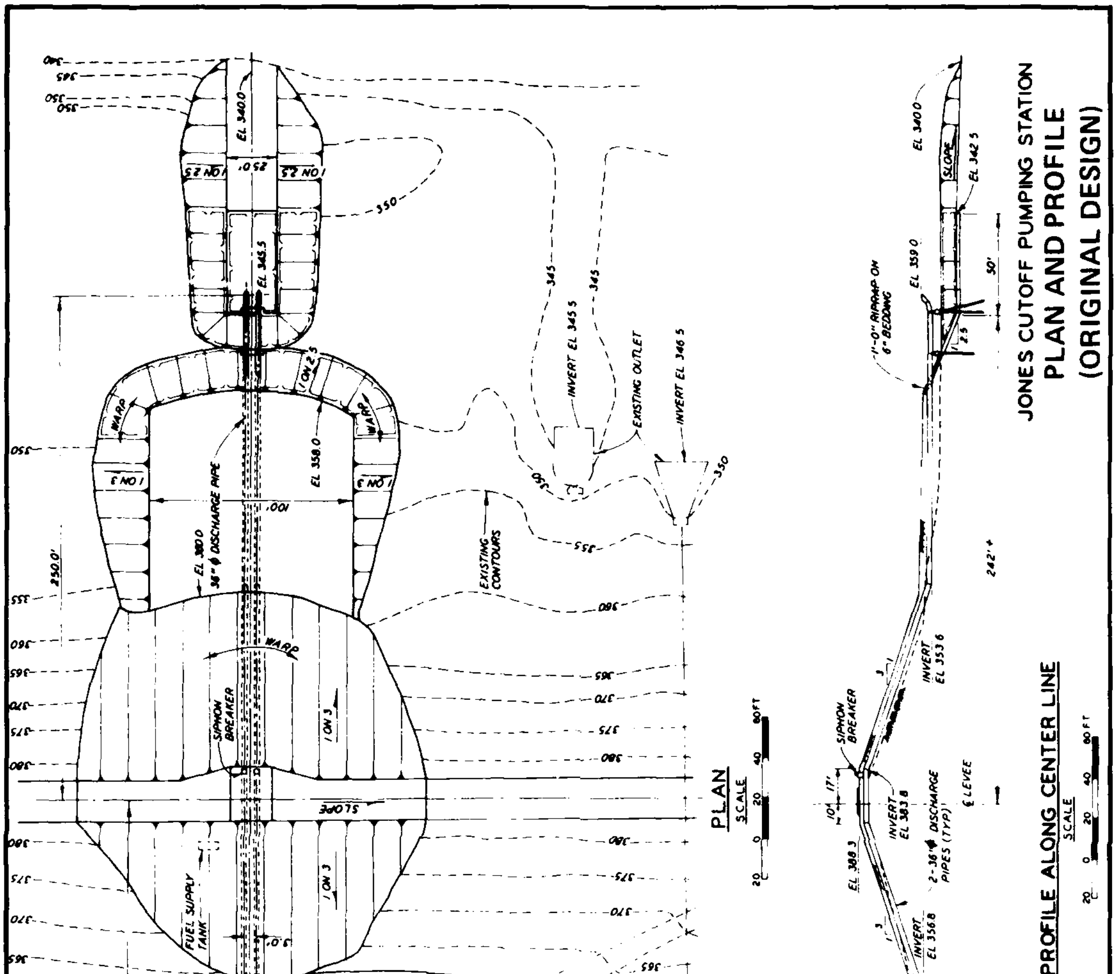

JONES CUTOFF PUMPING STATION
PLAN AND PROFILE
(ORIGINAL DESIGN)
PLAN
PROFILE ALONG CENTER LINE

PLATE 2

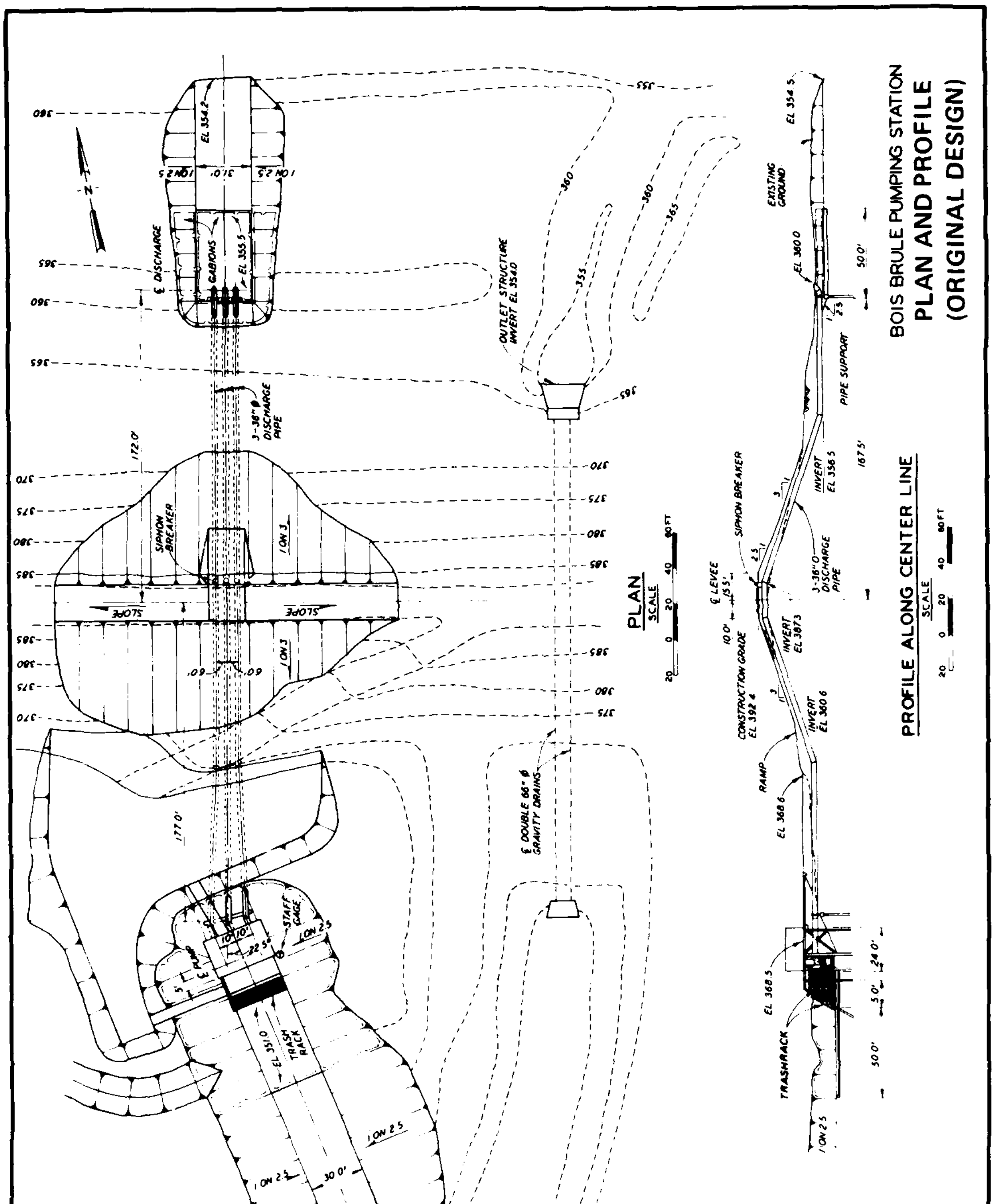

BOIS BRULE PUMPING STATION
PLAN AND PROFILE
(ORIGINAL DESIGN)
PLAN
SCALE
PROFILE ALONG CENTER LINE
SCALE
SIPHON BREAKER
3-36" Ø DISCHARGE PIPE
GABIONS
OUTLET STRUCTURE INVERT EL 354.0
℄ DOUBLE 66" Ø GRAVITY DRAINS
TRASH RACK
STAFF GAGE
FLOW
SLOPE
EXISTING GROUND
PIPE SUPPORT
CONSTRUCTION GRADE EL 392.4
RAMP
TRASHRACK
℄ LEVEE
℄ DISCHARGE

PLATE 3

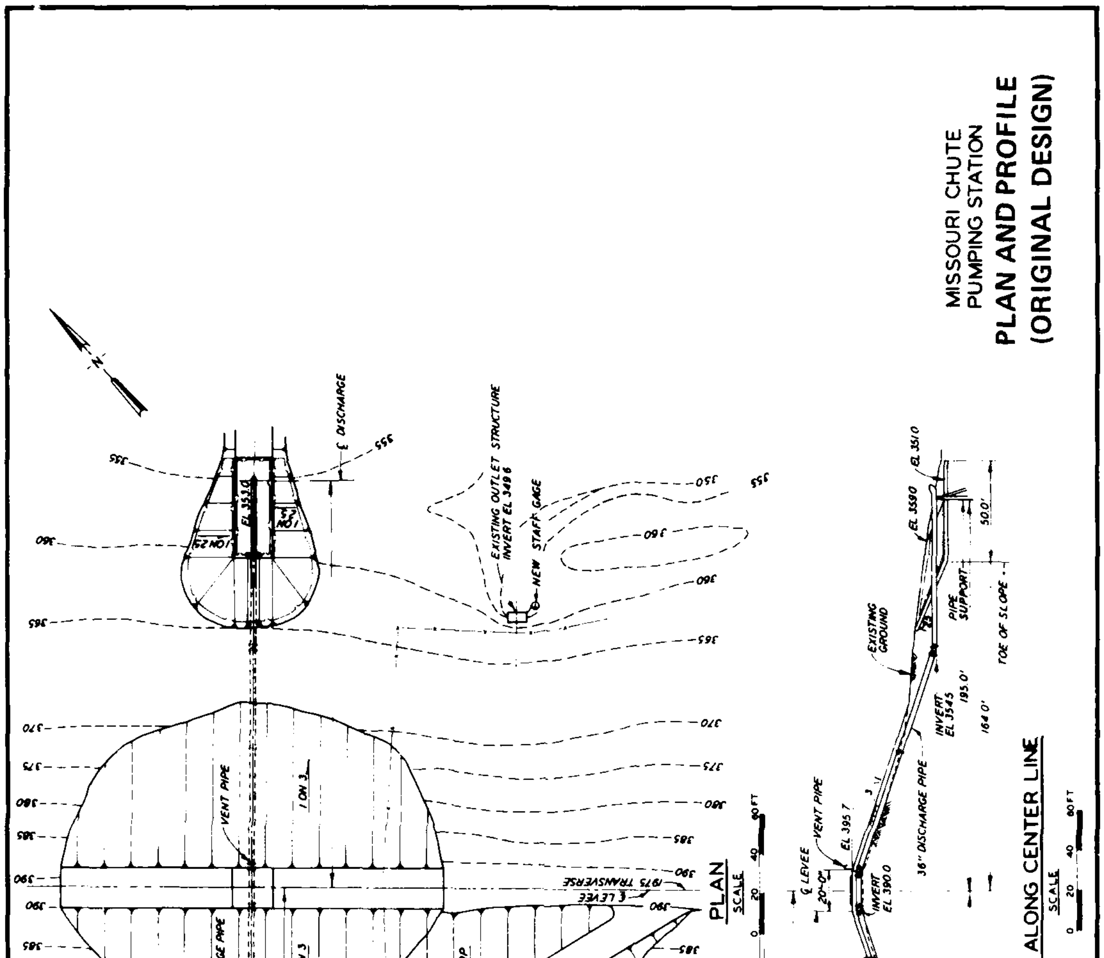
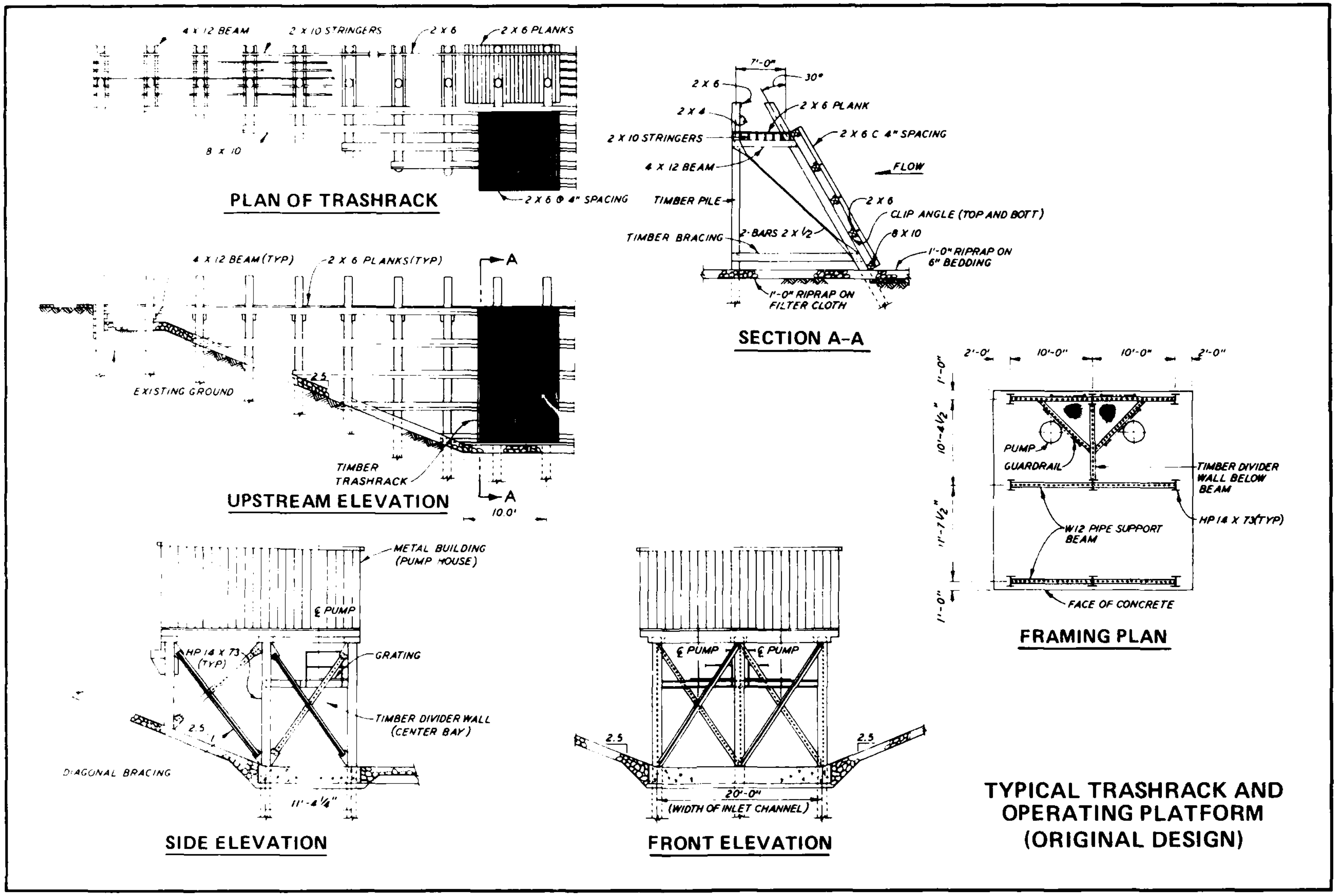
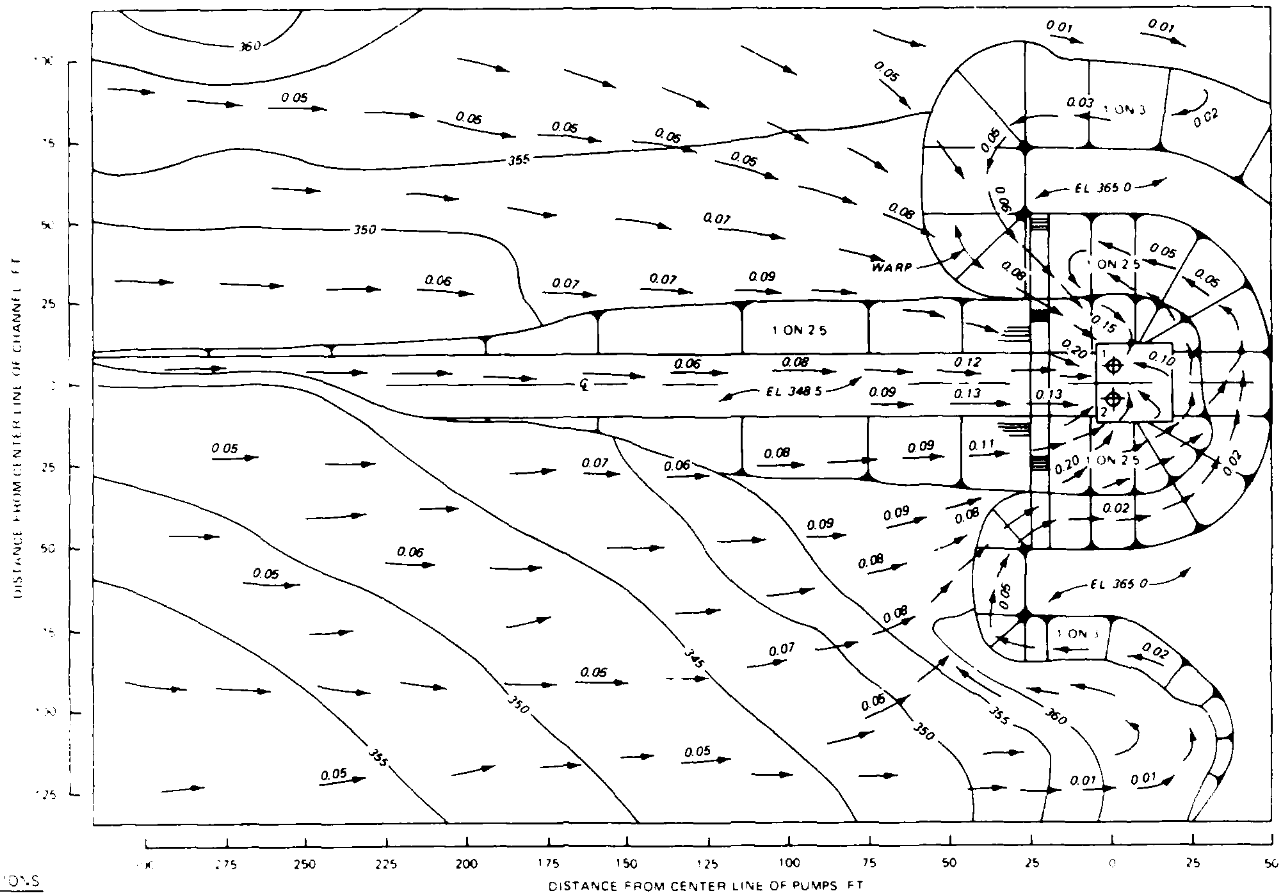

MISSOURI CHUTE
PUMPING STATION
PLAN AND PROFILE
(ORIGINAL DESIGN)
PLAN
SCALE
PROFILE ALONG CENTER LINE
SCALE
36" DISCHARGE PIPE
VENT PIPE
RAMP
WARP
OPERATOR HOUSE
EXISTING GROUND
TRASHRACK
PARKING AREA WITH 8" CRUSHED STONE SURFACE
EXISTING OUTLET STRUCTURE
NEW STAFF GAGE
TRANSITION TO MEET EXISTING DITCH
PIPE SUPPORT
TOE OF SLOPE

PLATE 4



TYPICAL TRASHRACK AND OPERATING PLATFORM (ORIGINAL DESIGN)



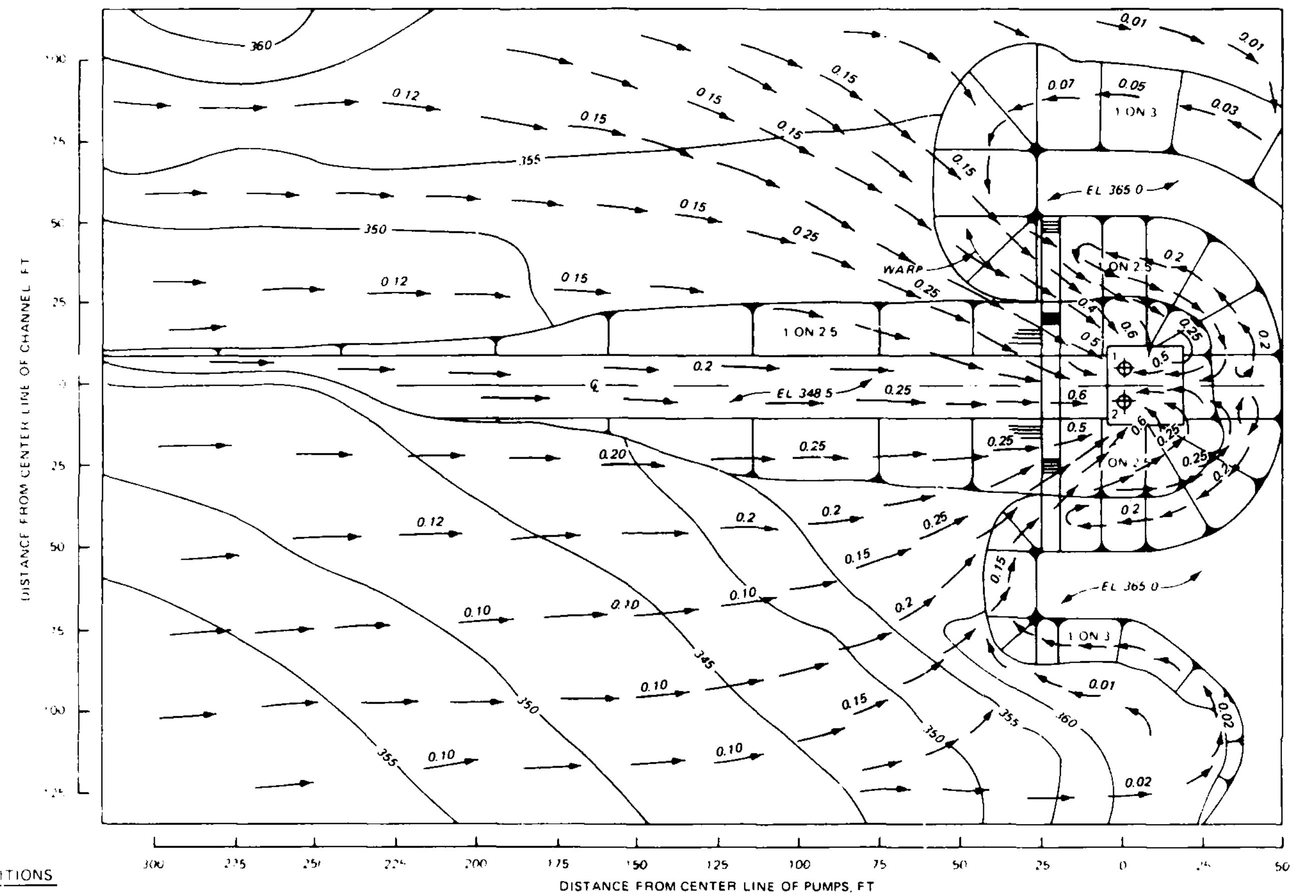
TEST CONDITIONS

PUMPS OPERATING	1
DISCHARGE PER PUMP	62.5 CFS
SUMP EL	358.0

NOTE VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE BOTTOM

CINQUE HOMMES

APPROACH BOTTOM CURRENT VELOCITIES
TYPE 1 SUMP
PUMP 1 OPERATING



TEST CONDITIONS

PUMPS OPERATING	1 & 2
DISCHARGE PER PUMP	62.5 CFS
SUMP EL	358.0

NOTE: VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE BOTTOM

CINQUE HOMMES
APPROACH BOTTOM CURRENT VELOCITIES
TYPE 1 SUMP
PUMPS 1 AND 2 OPERATING

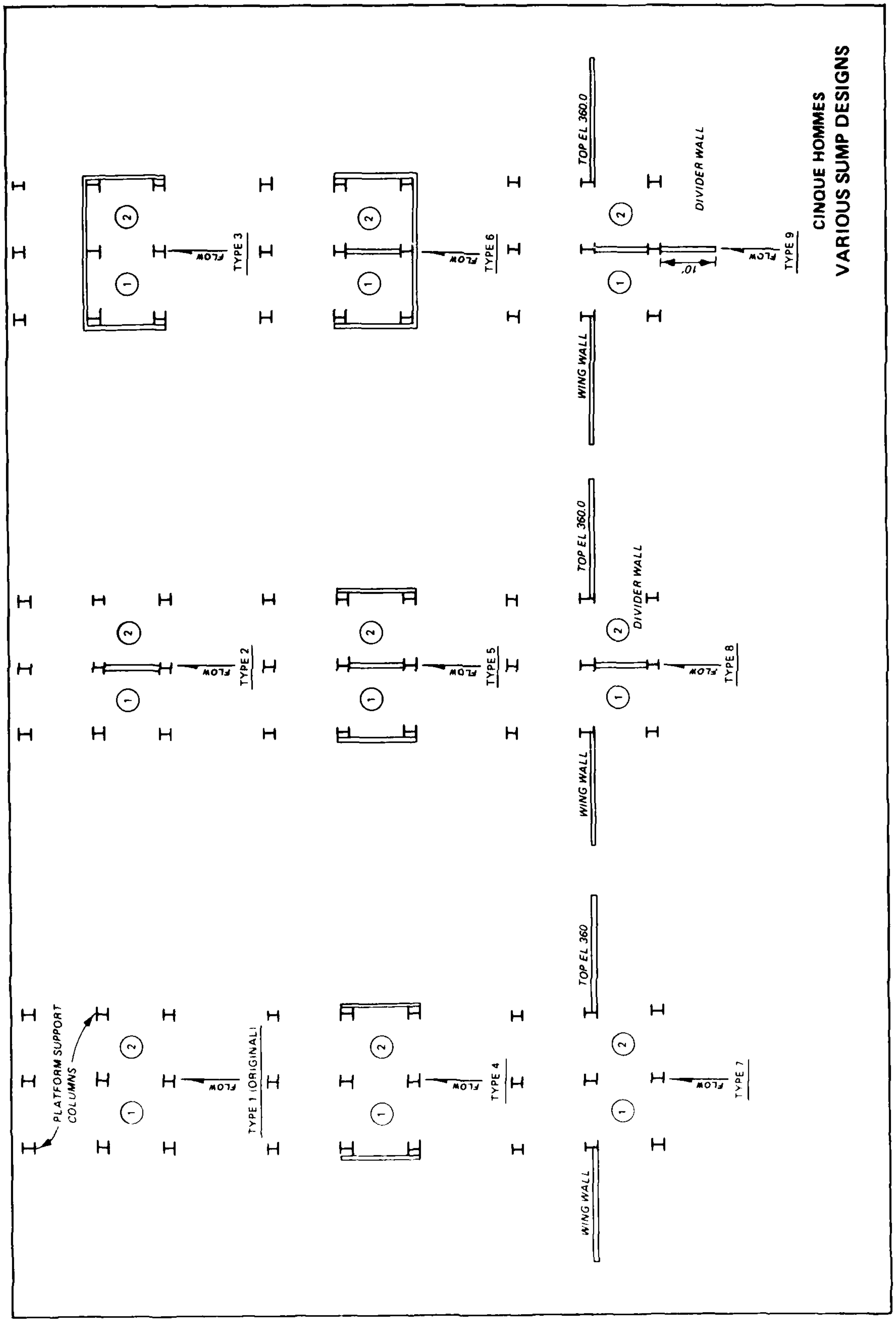
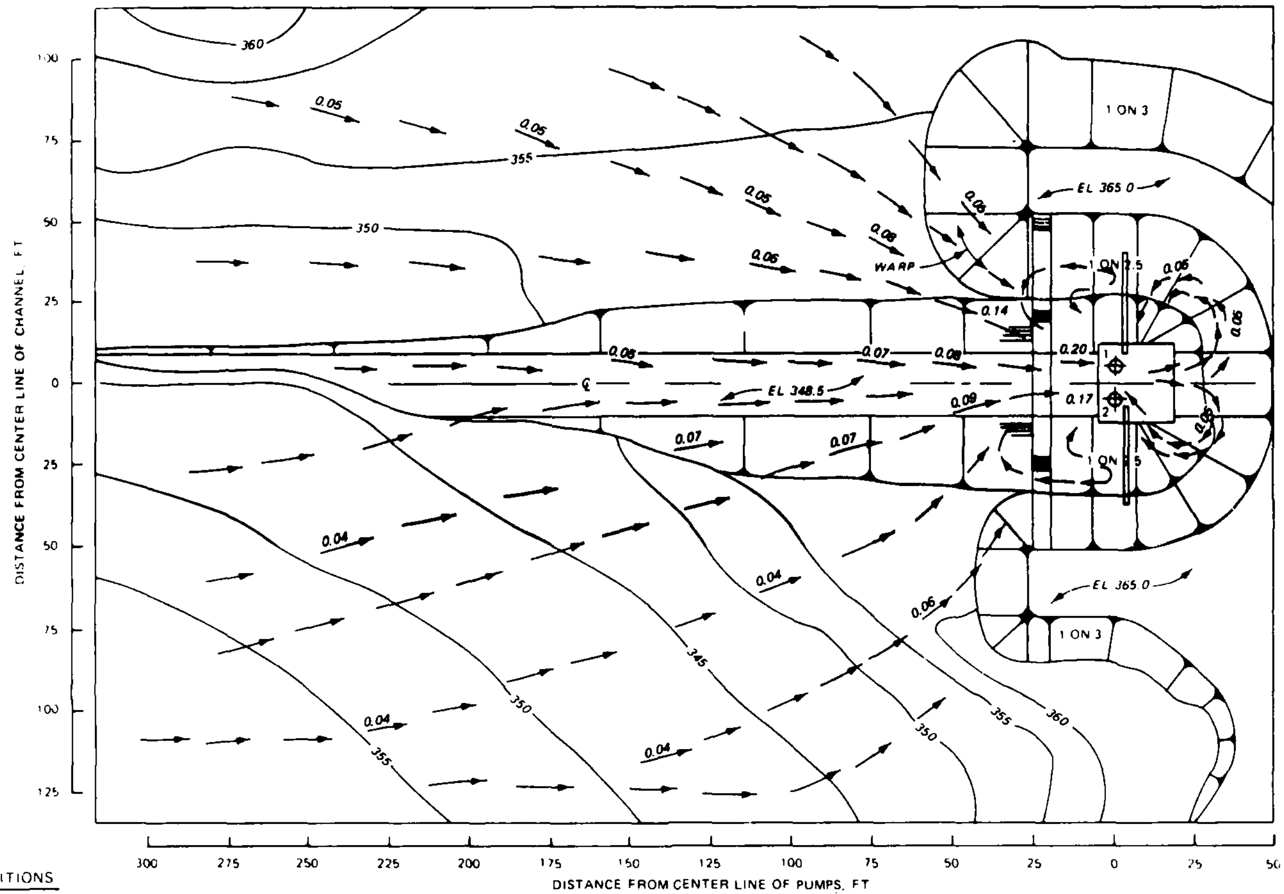

CINQUE HOMMES
VARIOUS SUMP DESIGNS
PLATFORM SUPPORT COLUMNS
TYPE 1 (ORIGINAL)
TYPE 2
TYPE 3
TYPE 4
TYPE 5
TYPE 6
TYPE 7
TYPE 8
TYPE 9
FLOW
WING WALL
TOP EL 360
TOP EL 360.0
DIVIDER WALL
10'
1
2

PLATE 8

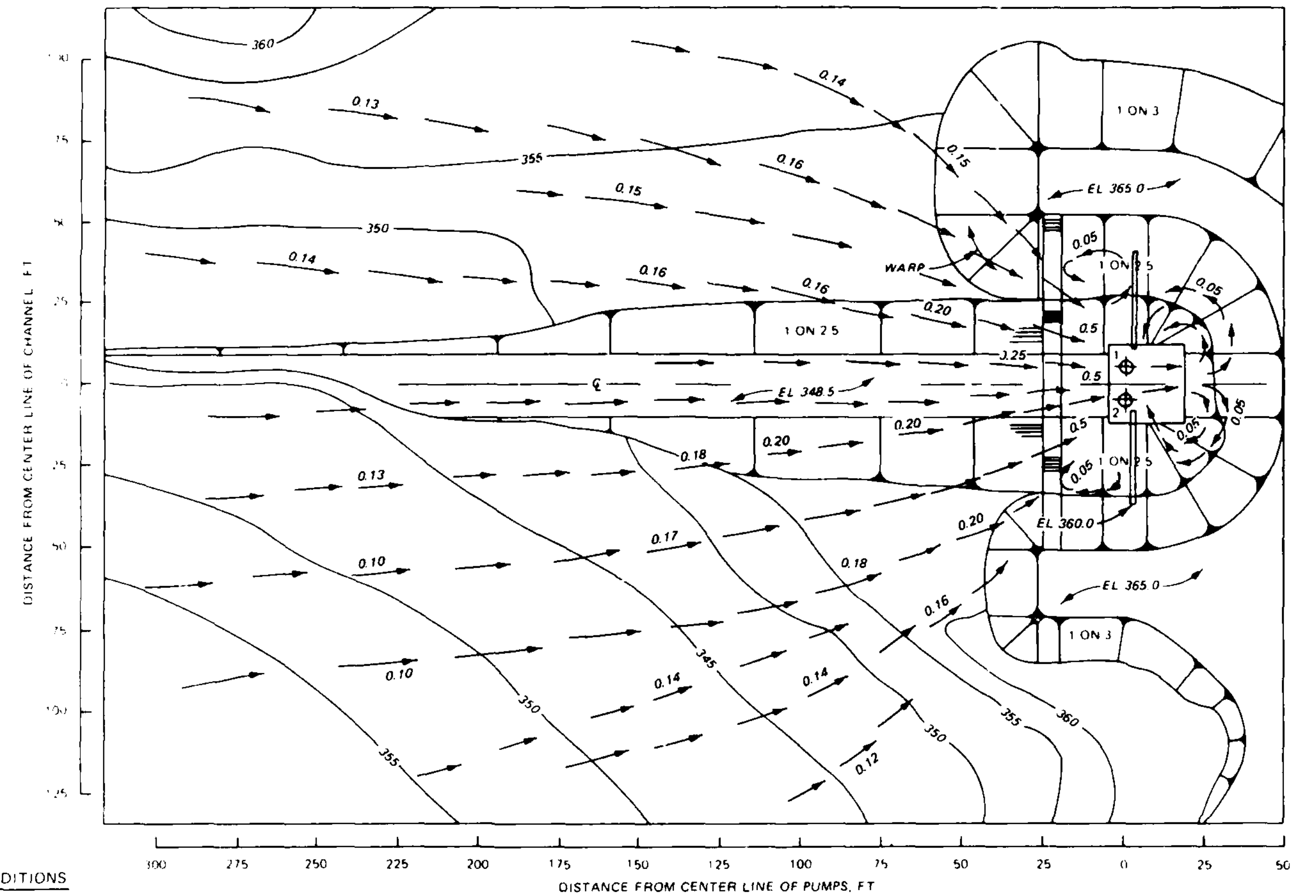


TEST CONDITIONS

PUMPS OPERATING	1
DISCHARGE PER PUMP	62 5 CFS
SUMP EL	358 5

NOTE VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE BOTTOM

CINQUE HOMMES
APPROACH BOTTOM CURRENT VELOCITIES
TYPE 7 SUMP (RECOMMENDED DESIGN)
PUMP 1 OPERATING



TEST CONDITIONS

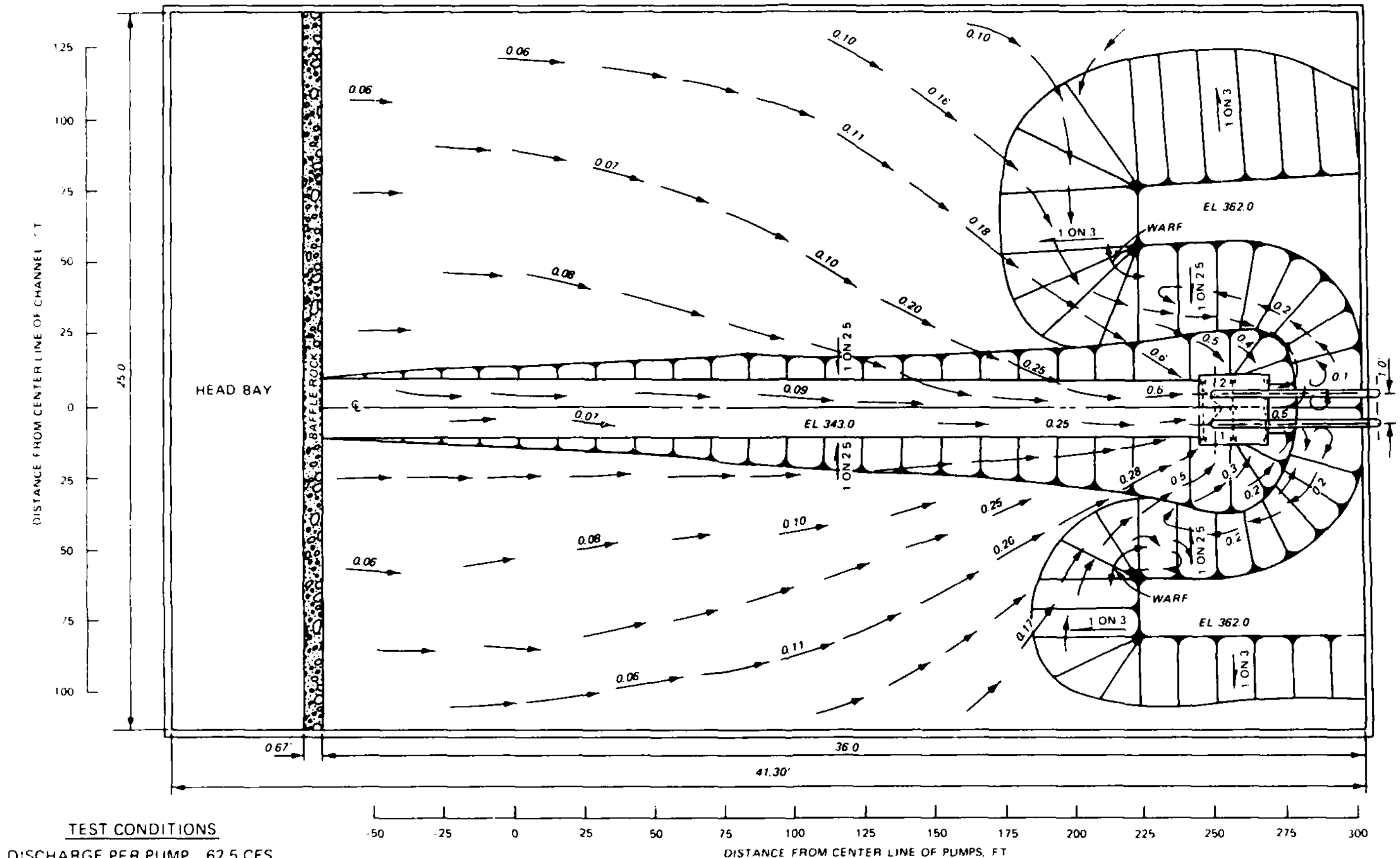
PUMPS OPERATING	1 & 2
DISCHARGE PER PUMP	62.5 CFS
SUMP EL	358.5

NOTE VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE BOTTOM

CINQUE HOMMES

APPROACH BOTTOM CURRENT VELOCITIES
TYPE 7 SUMP (RECOMMENDED DESIGN)

PUMPS 1 AND 2 OPERATING

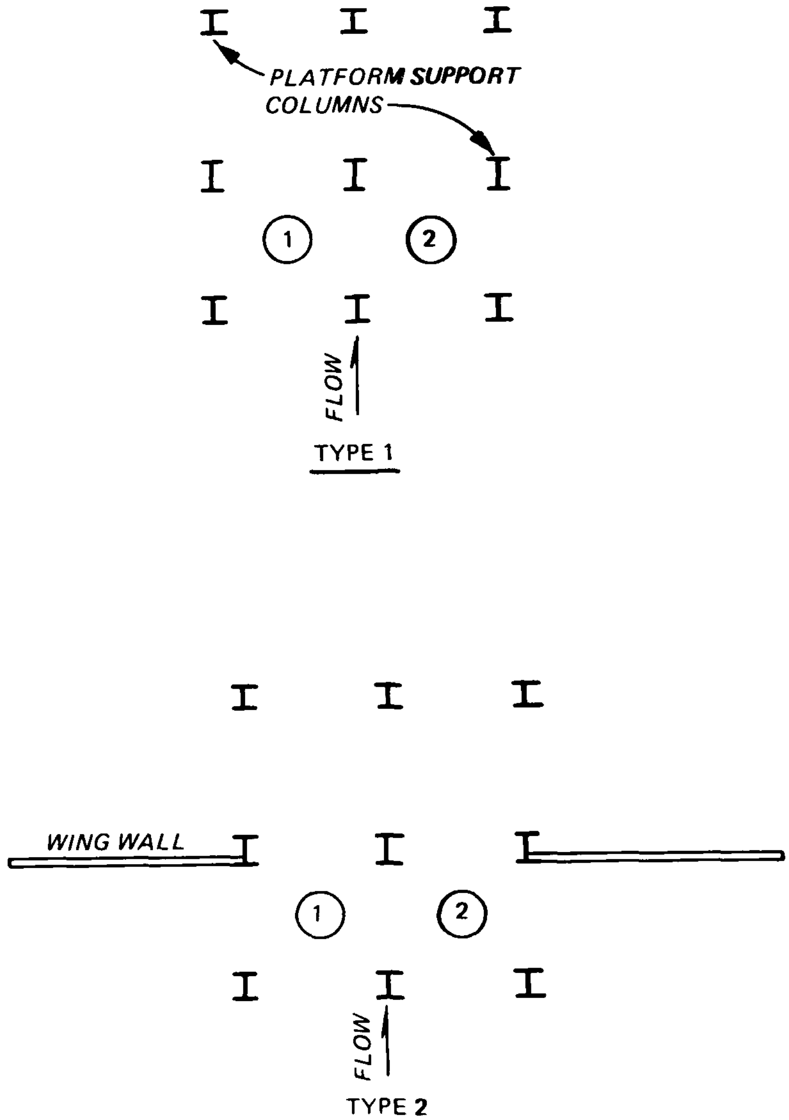


TEST CONDITIONS

DISCHARGE PER PUMP 62.5 CFS
SUMP EL 351.0

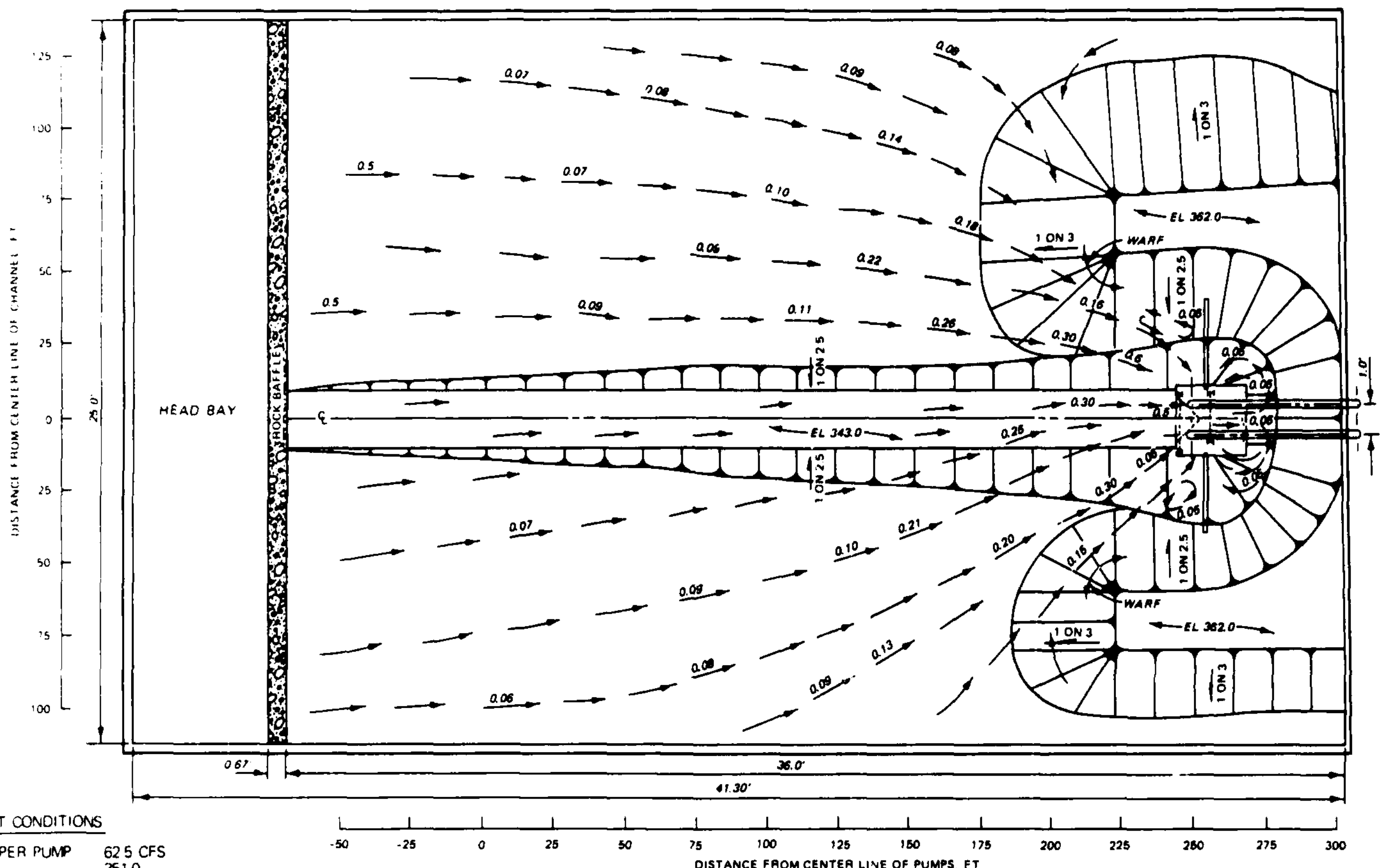
NOTE VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE BOTTOM

JONES CUTOFF
APPROACH BOTTOM CURRENT VELOCITIES
TYPE 1 SUMP
PUMPS 1 AND 2 OPERATING



JONES CUTOFF
TYPES 1 AND 2 SUMPS

PLATE 12



TEST CONDITIONS

DISCHARGE PER PUMP	62.5 CFS
SUMP EL	351.0

NOTE: VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE BOTTOM

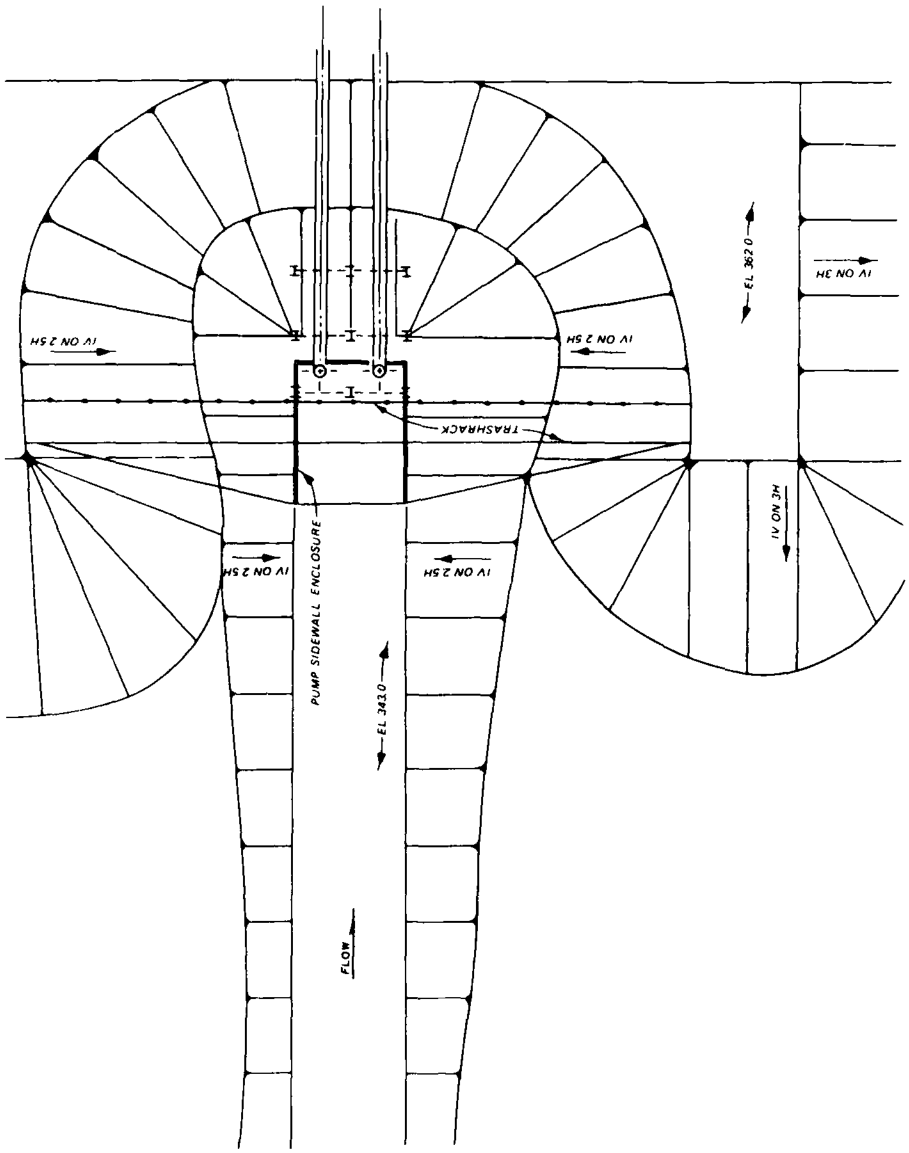
JONES CUTOFF

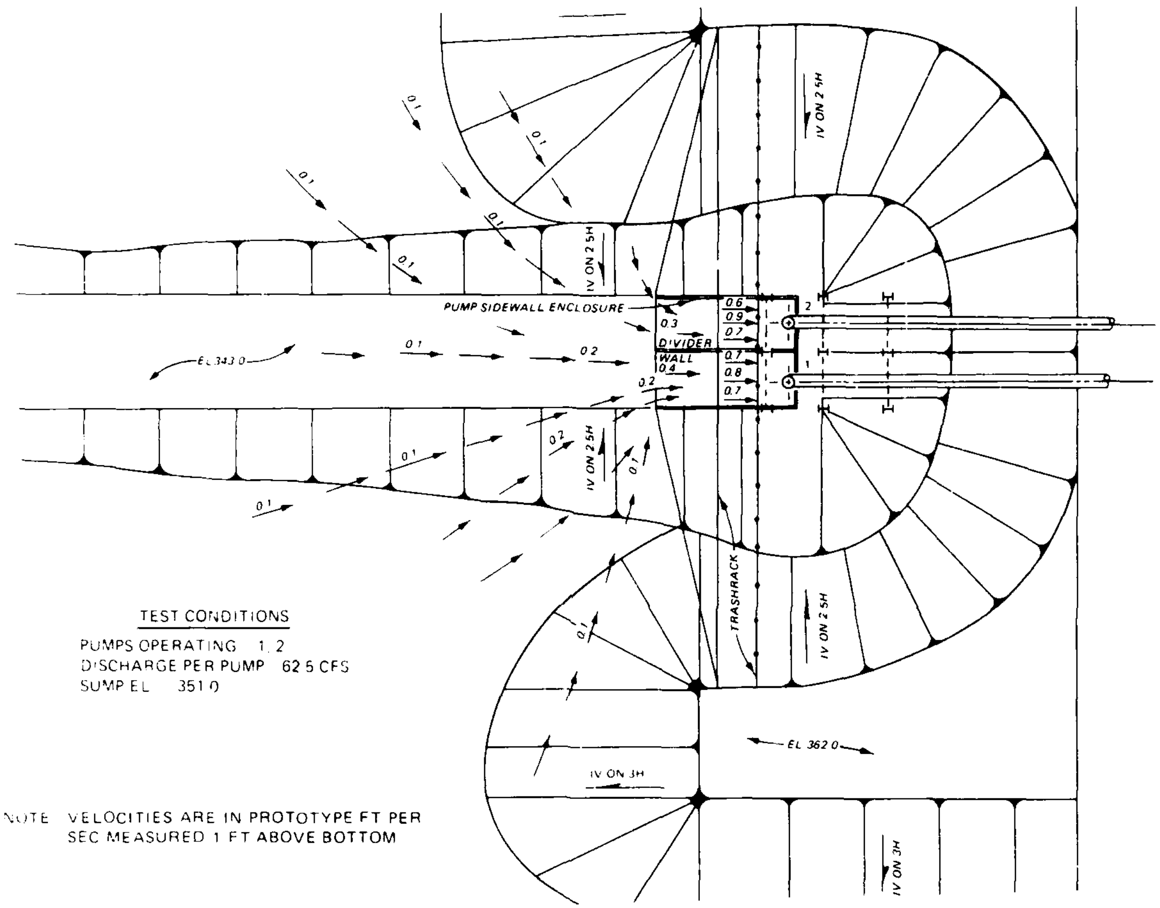
APPROACH BOTTOM CURRENT VELOCITIES

TYPE 2 SUMP

PUMPS 1 AND 2 OPERATING

JONES CUTOFF
TYPE 3 SUMP



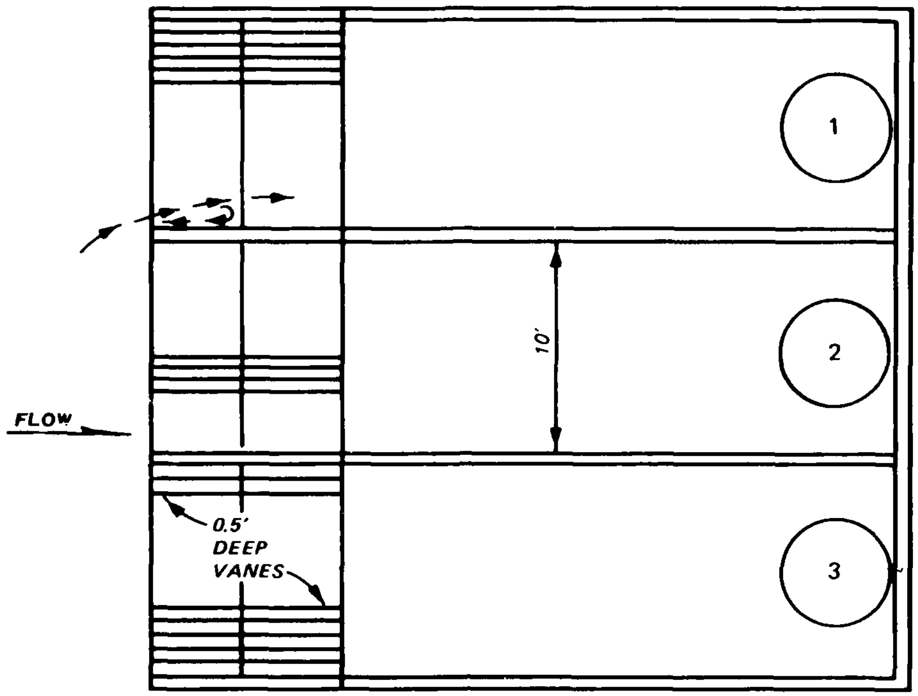


TEST CONDITIONS

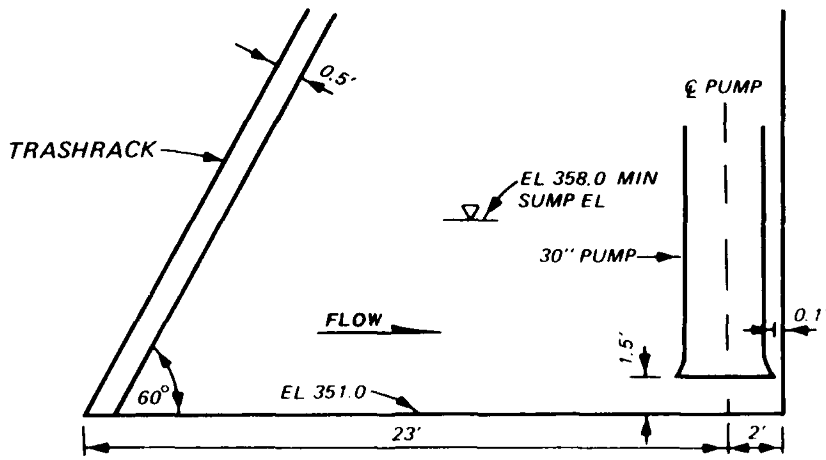
PUMPS OPERATING 1, 2
DISCHARGE PER PUMP 62.5 CFS
SUMP EL 351.0

NOTE VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE BOTTOM

JONES CUTOFF
APPROACH CURRENT VELOCITIES
TYPE 4 SUMP

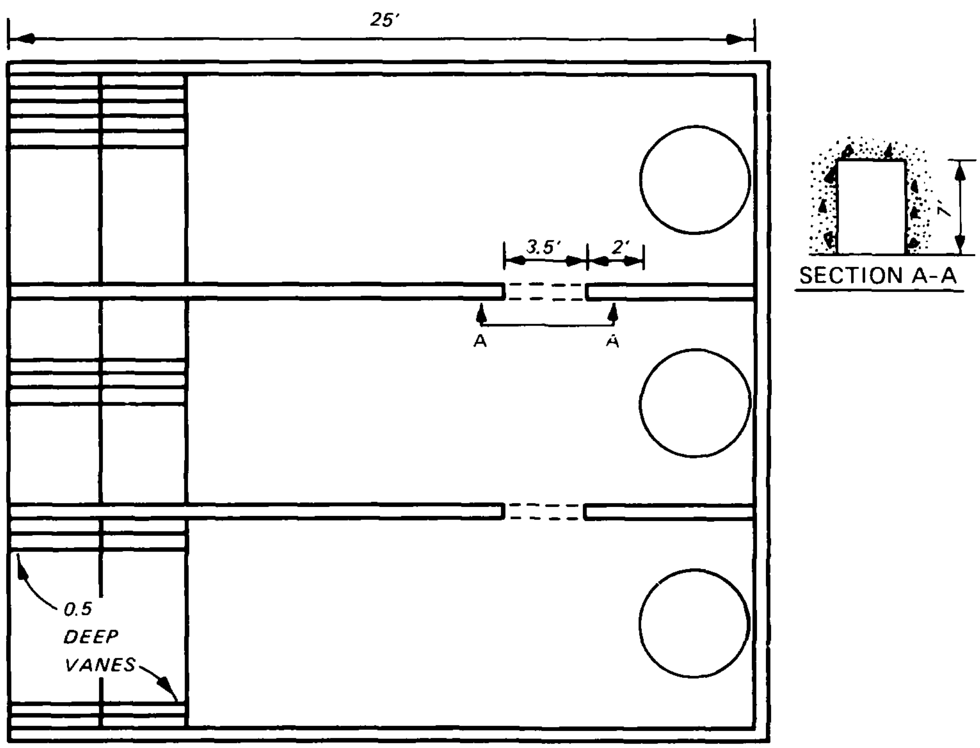


a. PLAN VIEW

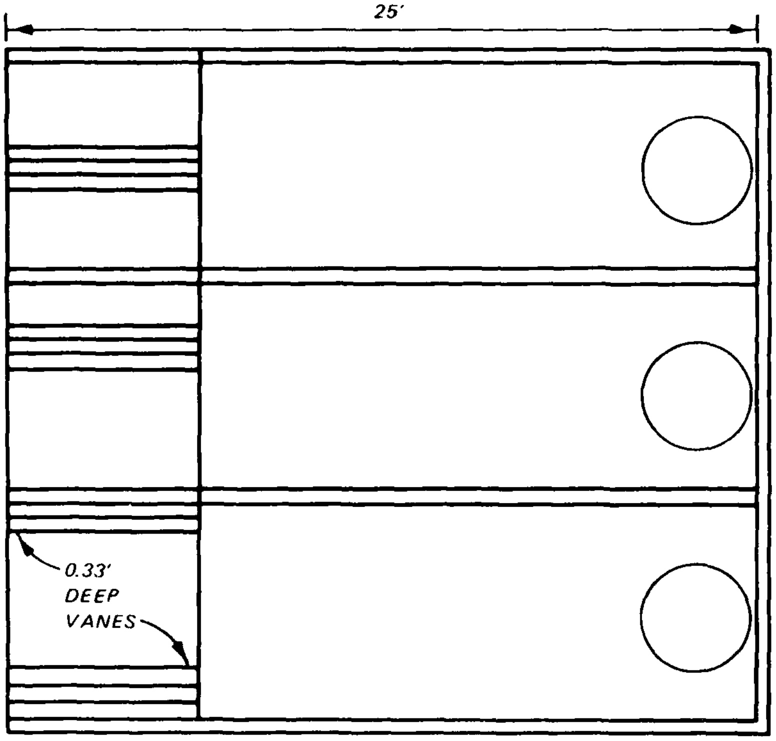


b. PROFILE VIEW

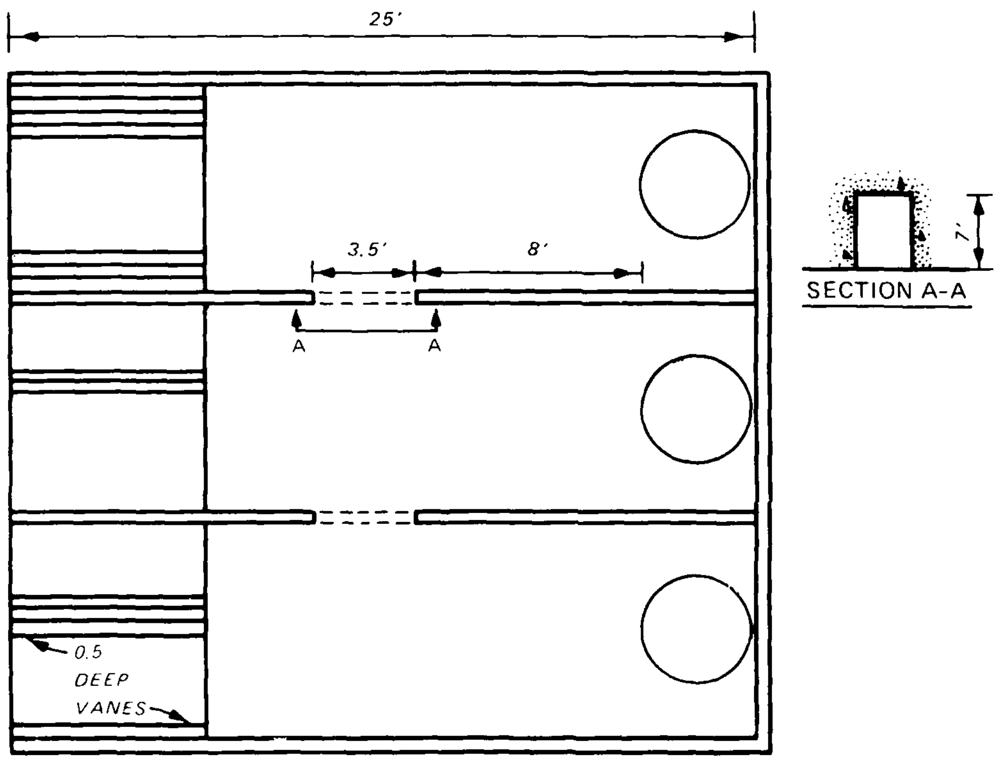
BOIS BRULE
TYPE 1 SUMP, TYPE 1 TRASHRACK



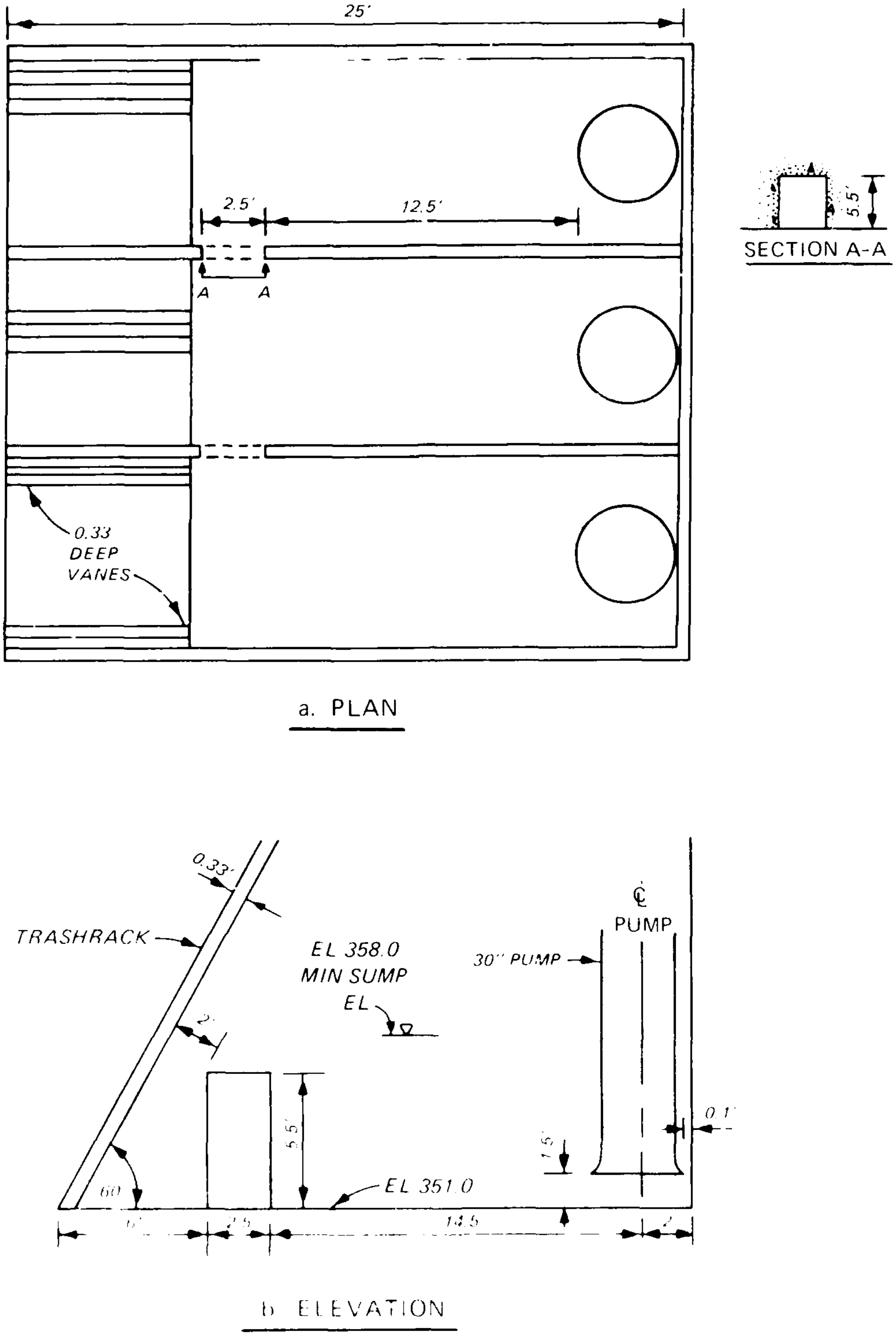
BOIS BRULE
TYPE 2 SUMP, TYPE 1 TRASHRACK



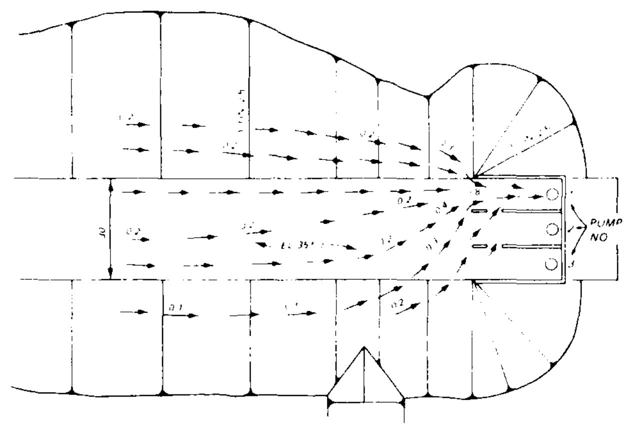
BOIS BRULE
TYPE 1 SUMP, TYPE 2 TRASHRACK



BOIS BRULE
TYPE 3 SUMP, TYPE 1 TRASHRACK

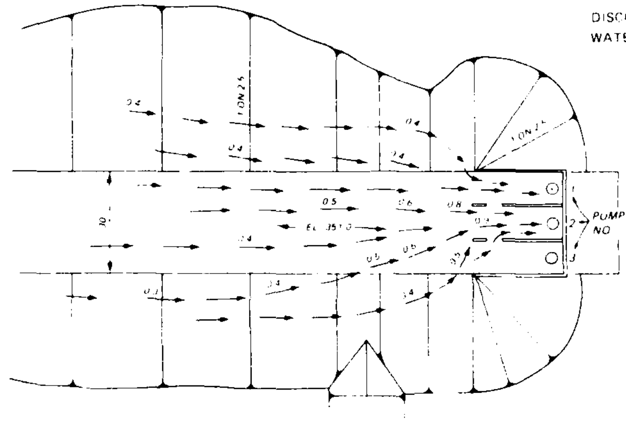


BOIS BRULE
TYPE 4 SUMP, TYPE 2 TRASHRACK



a. PUMP 1 OPERATING

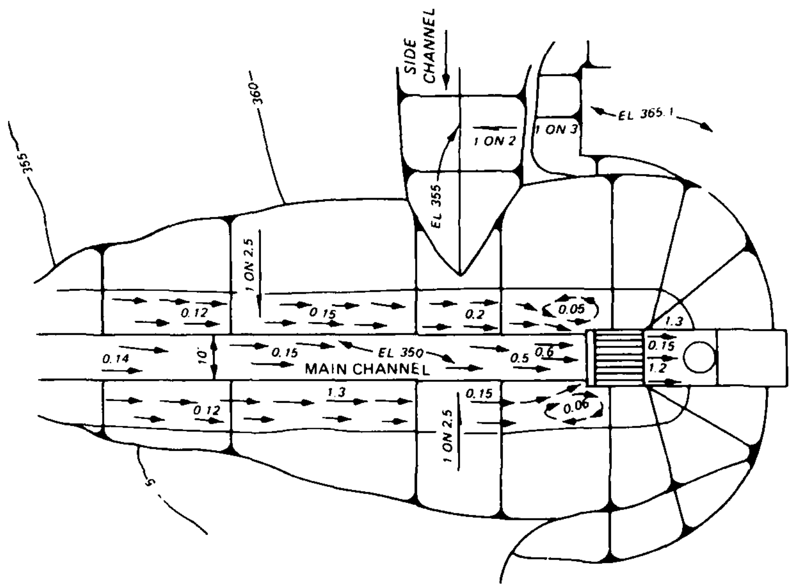
TEST CONDITIONS
DISCHARGE PER PUMP 72 CFS
WATER-SURFACE EL 358.0



b. PUMPS 1 AND 2 OPERATING

c. PUMPS 1, 2, AND 3 OPERATING

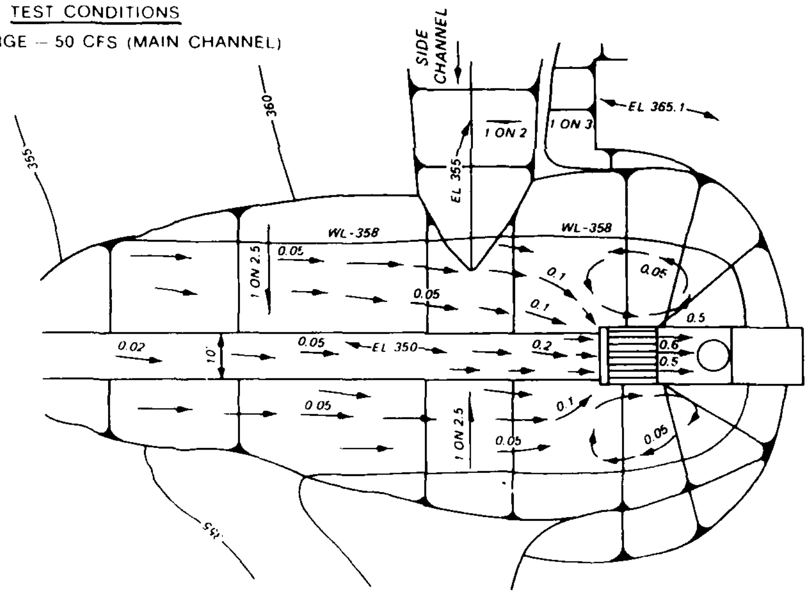
BOIS BRULE
APPROACH CURRENT VELOCITIES
TYPE 4 SUMP, TYPE 2 TRASHRACK



a. WATER-SURFACE EL 354.0

TEST CONDITIONS

DISCHARGE – 50 CFS (MAIN CHANNEL)



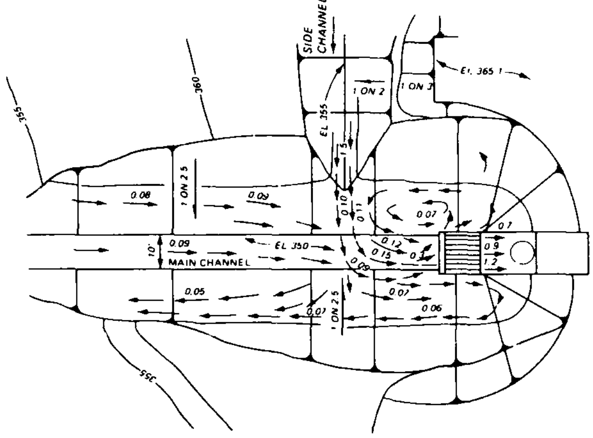
b. WATER-SURFACE EL 358.0

NOTE VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE THE BOTTOM

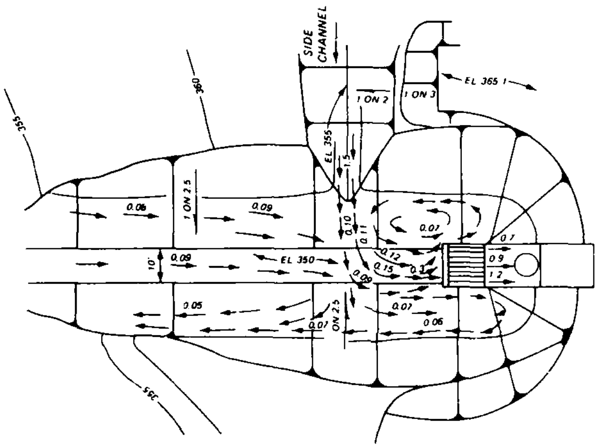
MISSOURI CHUTE
(MAIN CHANNEL)
APPROACH BOTTOM CURRENT VELOCITIES

TEST CONDITIONS

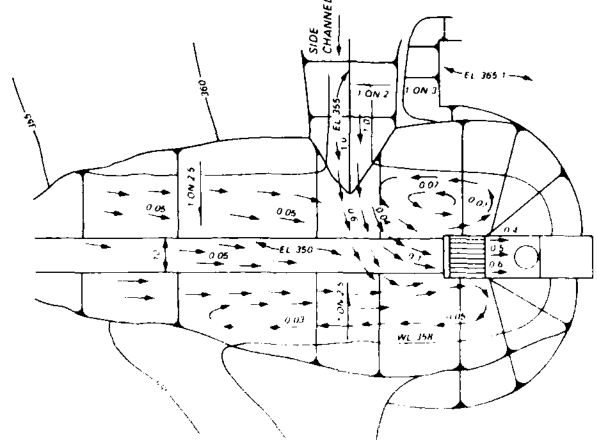
DISCHARGE 30 CFS (MAIN CHANNEL)
20 CFS (SIDE CHANNEL)



a. WATER-SURFACE EL 354.0



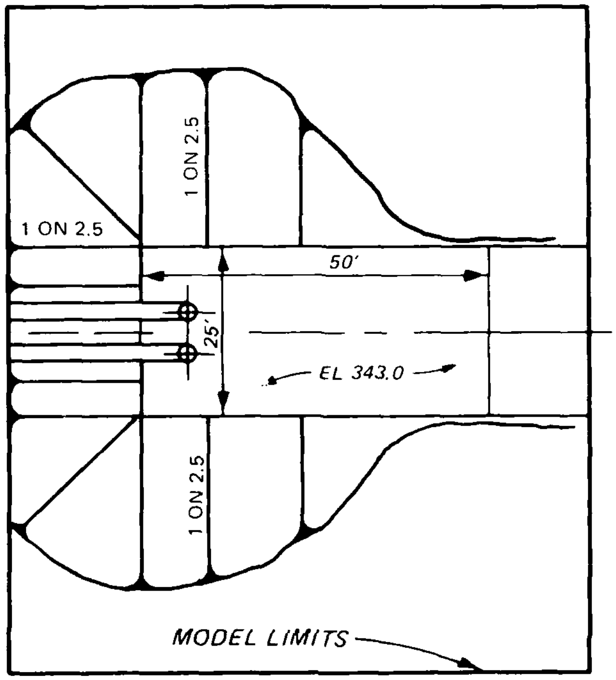
b. WATER-SURFACE EL 356.0



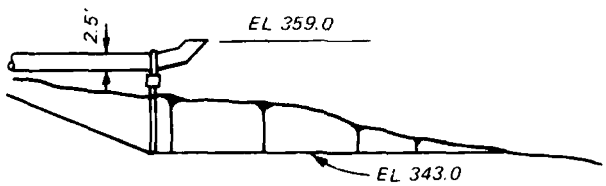
c. WATER-SURFACE EL 358.0

NOTE: VELOCITIES ARE IN PROTOTYPE FT PER SEC MEASURED 1 FT ABOVE THE BOTTOM

MISSOURI CHUTE
(MAIN AND SIDE CHANNEL)
APPROACH BOTTOM CURRENT VELOCITIES

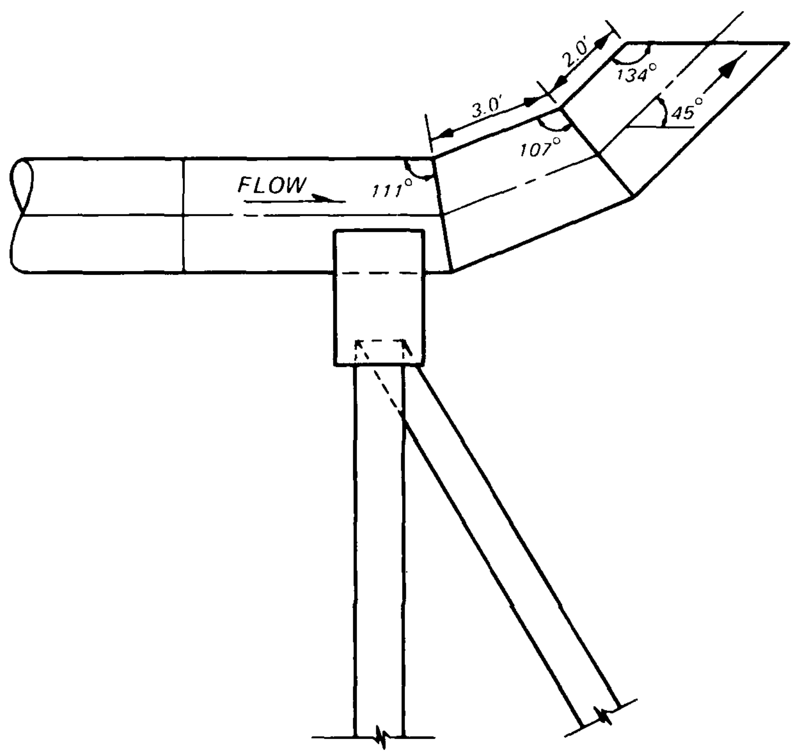


PLAN



ELEVATION

CINQUE HOMMES
DISCHARGE OUTLETS
TYPE 1 DESIGN

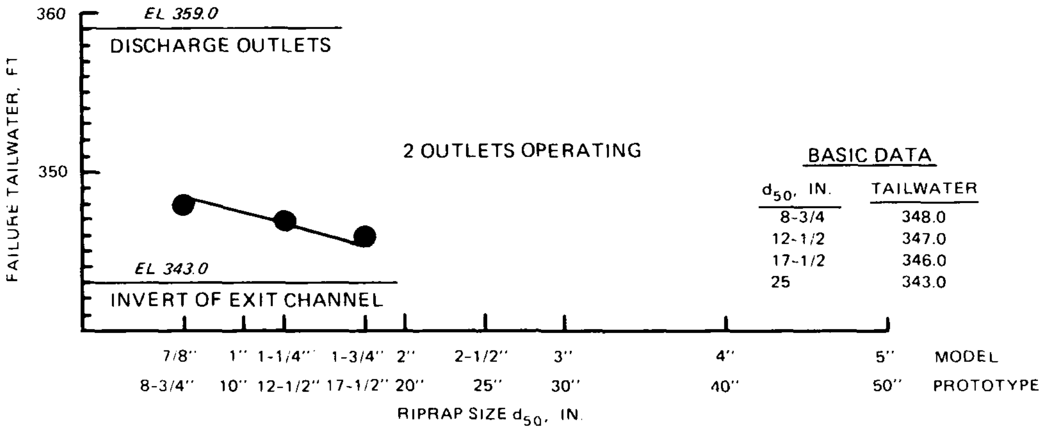


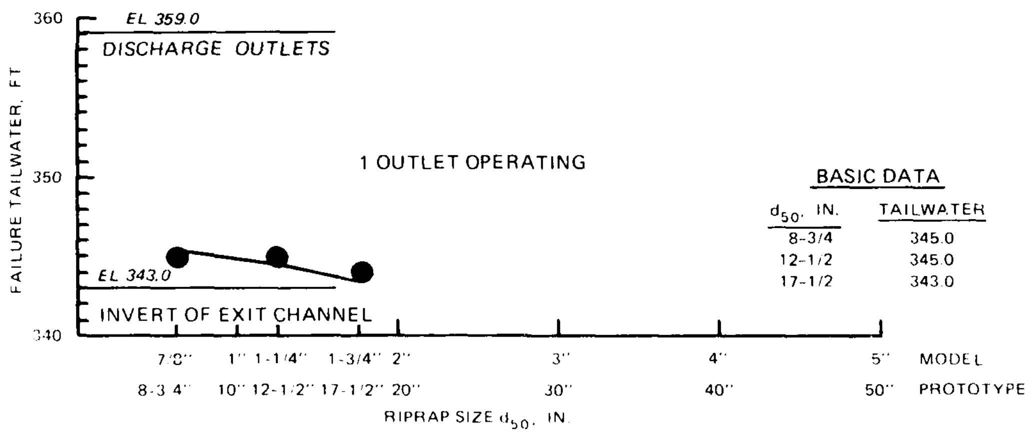
TYPICAL 45-DEG SAXOPHONE OUTLET
DISCHARGE OUTLET

TEST CONDITIONS

DISCHARGE PER OUTLET 62.5 CFS

TYPE 1 DESIGN (45°)





CINQUE HOMMES

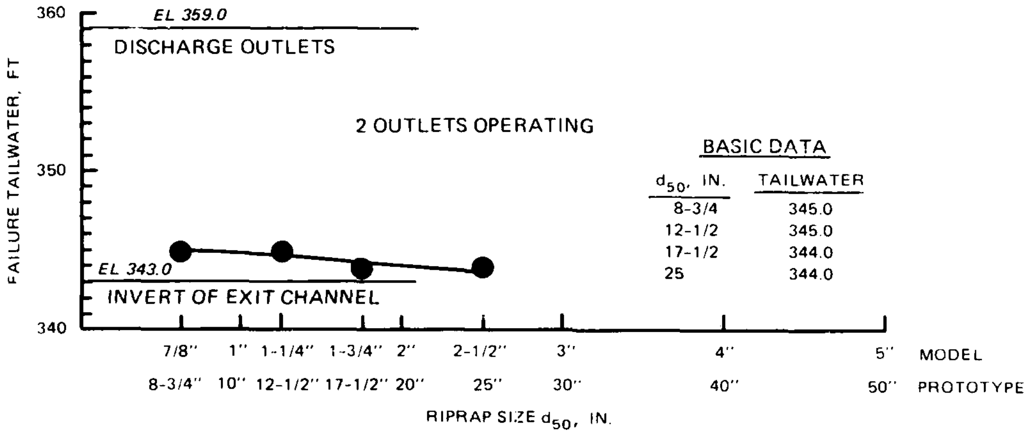
RIPRAP INVESTIGATION - OUTLET STRUCTURE

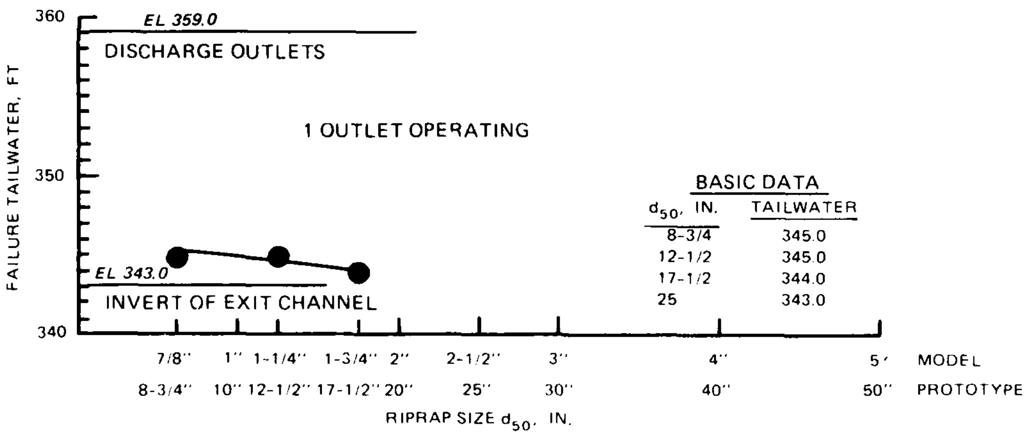
TYPE 1 DESIGN

TEST CONDITIONS

DISCHARGE PER OUTLET 62.5 CFS

TYPE 2 DESIGN (90°)





CINQUE HOMMES

RIPRAP INVESTIGATION - OUTLET STRUCTURE

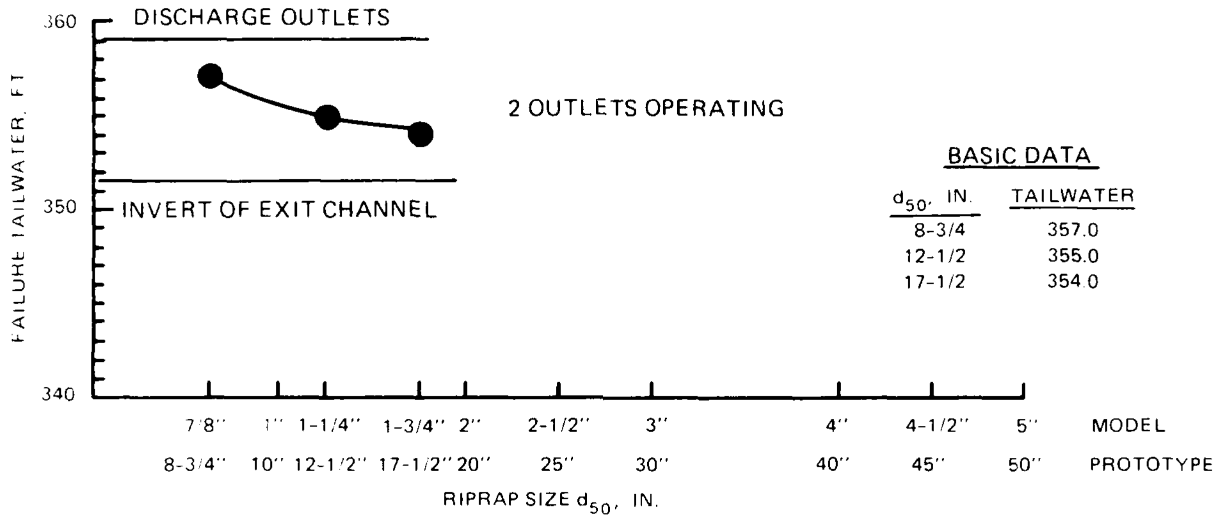
TYPE 2 DESIGN

CINQUE HOMMES

RIPRAP INVESTIGATION - OUTLET STRUCTURE
TYPE 3 DESIGN

TEST CONDITIONS

NATURALLY CONTOURED SIDE SLOPES
DISCHARGE PER OUTLET 62.5 CFS
TYPE 3 DESIGN (45°)

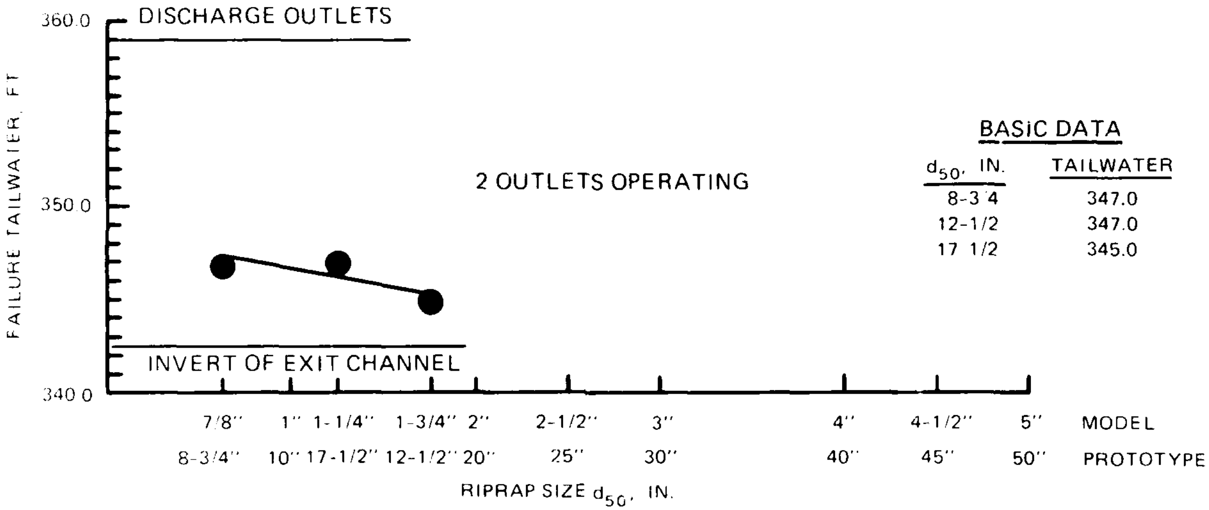


BASIC DATA

d_{50}, IN.	TAILWATER
8-3/4	357.0
12-1/2	355.0
17-1/2	354.0

TEST CONDITIONS

DISCHARGE PER OUTLET 62.5 CFS
DISCHARGE OUTLET DIAM 36 IN.



BASIC DATA

d_{50}, IN.	TAILWATER
8-3/4	347.0
12-1/2	347.0
17 1/2	345.0

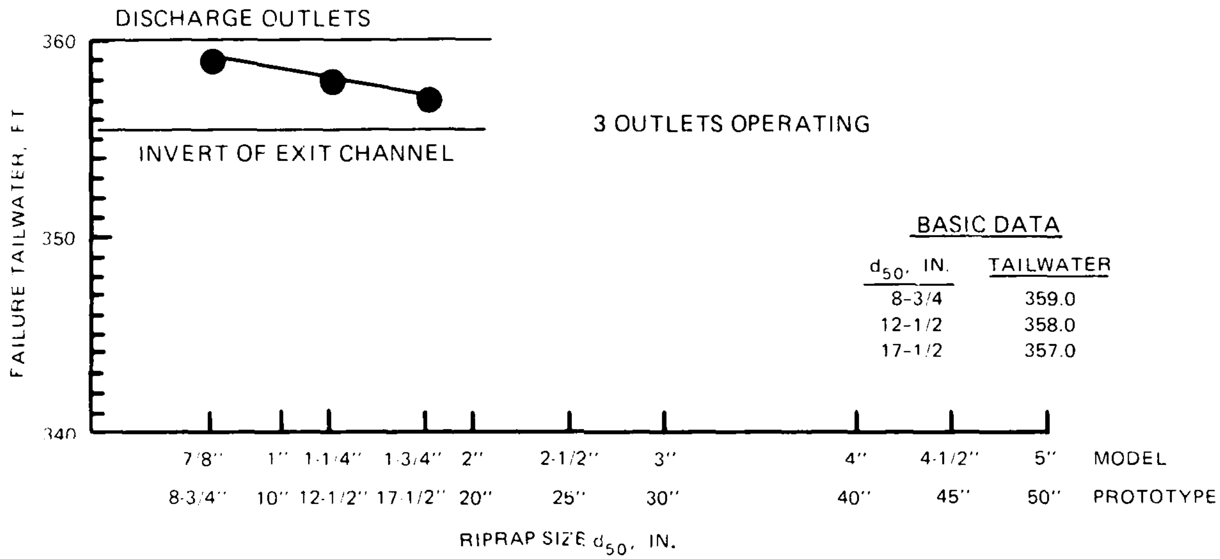
NOTE STONE HAVING A d_{50} OF 25 IN. (PROTOTYPE) WAS STABLE FOR ANY TAILWATER ELEVATION

JONES CUTOFF

RIPRAP INVESTIGATION - OUTLET STRUCTURE
TYPE 1 DESIGN

TEST CONDITIONS

DISCHARGE PER OUTLET	72.5 CFS
DISCHARGE OUTLET DIAM	36 IN



BASIC DATA

d_{50}, IN.	TAILWATER
8-3/4	359.0
12-1/2	358.0
17-1/2	357.0

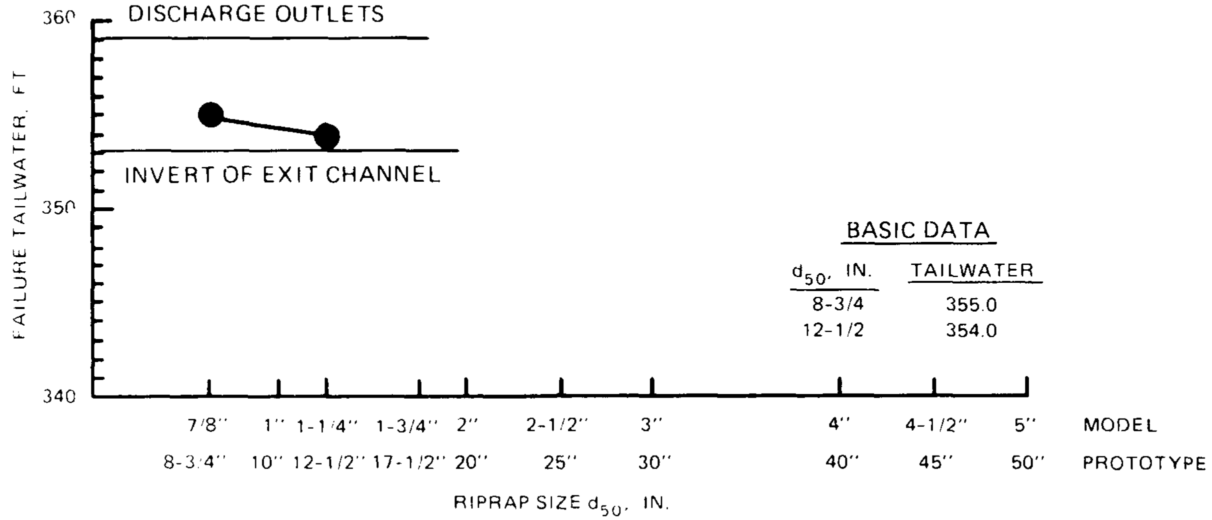
NOTE: STONE HAVING A d_{50} OF 25" (PROTOTYPE) WAS STABLE FOR ANY TAILWATER ELEVATION.

BOIS BRULE

RIPRAP INVESTIGATION - OUTLET STRUCTURE

TEST CONDITIONS

DISCHARGE PER OUTLET	50 CFS
DISCHARGE OUTLET DIAM	36 IN.



BASIC DATA

d_{50}, IN.	TAILWATER
8-3/4	355.0
12-1/2	354.0

NOTE: STONE HAVING A d_{50} OF 17-1/2 IN. (PROTOTYPE) WAS STABLE FOR ANY TAILWATER ELEVATION

MISSOURI CHUTE

RIPRAP INVESTIGATION - OUTLET STRUCTURE

TYPE 1 DESIGN